XXVIII Rencontres de Physique de la Vallée d'Aoste

On the recent anomalies in B decays

Pietro Biancofiore
Università di Bari & INFN

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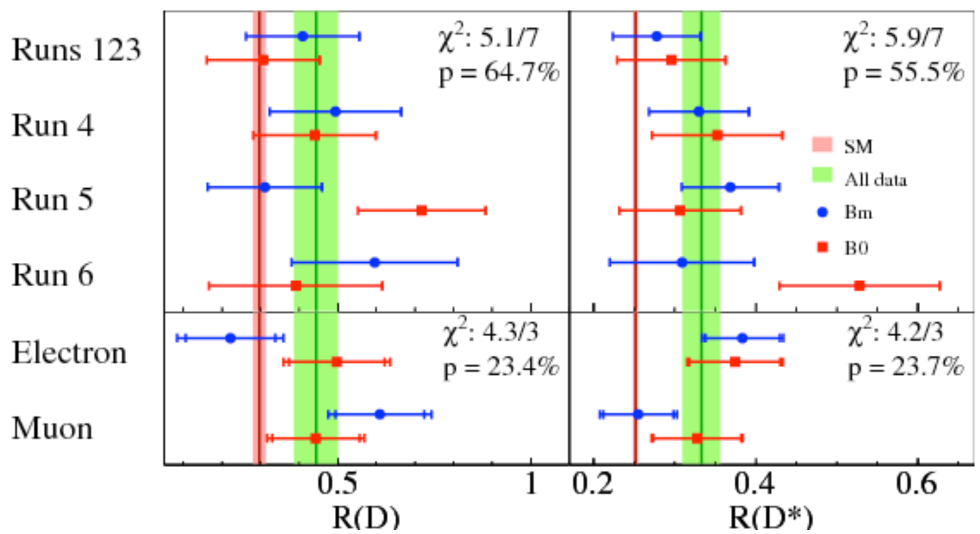
Experimental results

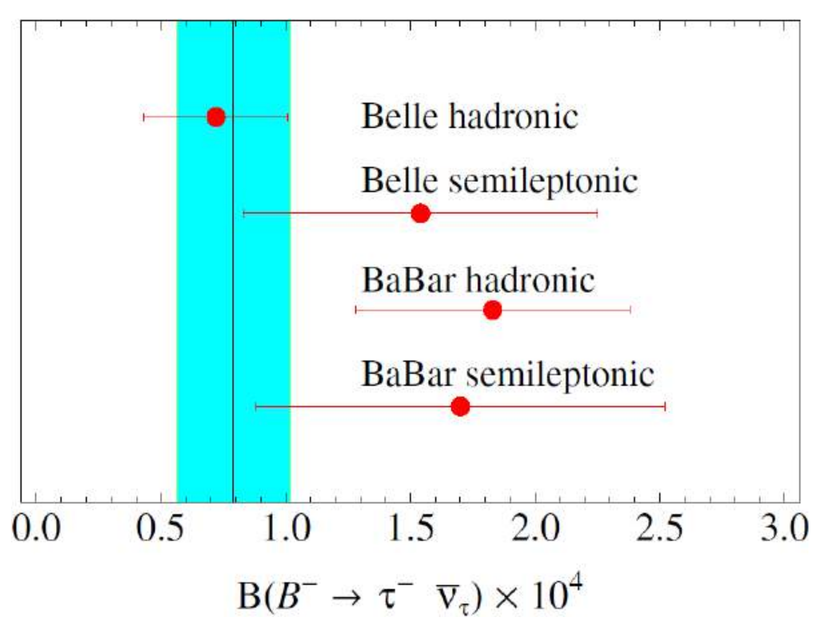
The BABAR Collaboration reported the measurements [PRL, 109 (2012) 101802]

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\mu\bar{\nu}_\mu)}$$



$$\mathcal{R}^-(D) = 0.429 \pm 0.082 \pm 0.052$$
$$\mathcal{R}^-(D^*) = 0.322 \pm 0.032 \pm 0.022$$
$$\mathcal{R}^0(D^*) = 0.355 \pm 0.039 \pm 0.021$$
$$\mathcal{R}^0(D) = 0.469 \pm 0.084 \pm 0.053$$

- BABAR quotes 3.4σ deviation from SM
- Is there a possible relation with $B \to \tau\nu_\tau$?



... however

new measurements are much more compatible with SM than the previous ones.

for V_{cb} = 0.0035 ± 0.0005

Theoretical explanation of the anomaly (I)

In a New Physics scenario, a possible explanation is the exchange of new scalars that couple to leptons proportional to their masses, with two main consequences:

- enhancement of the modes with τ in the final states
- both purely leptonic and semileptonic channels would be affected

... but

The simplest framework of 2HDM-II is excluded by the BABAR fit:
no choice of parameters simultaneously reproduces the experimental data on R(D) and R(D*)

- Fajfer et al, PRD 85 (2012) 094025
- Fajfer et al, PRL 109 (2012) 161801
- Crivellin et al, PRD 86 (2012) 054014
- Datta et al, PRD 86 (2012) 034027
- Choudury et al, PRD 86 (2012) 114037
- Celis et al,JHEP 1301 (2013) 054
- Tanaka et al, PRD 87 (2013) 034028
- Dorsner et al, JHEP 1311 (2013) 084

Theoretical explanation of the anomaly (II)

Let us consider a New Physics scenario in which:
- only the semileptonic modes are enhanced but not the purely leptonic ones
- can be tested in similar modes via suitable observables

[P.B., P. Colangelo and F. De Fazio PRD 87 (2013) 074010]

$$\mathcal{H}_{\rm eff} = \frac{G_F}{\sqrt{2}}\Big[\underbrace{\bar{c}\gamma_\mu(1-\gamma_5)b\bar{\ell}\gamma^\mu(1-\gamma_5)\bar{\nu}_\ell}_{\rm SM} + \epsilon_T^\ell \underbrace{\bar{c}\sigma_{\mu\nu}(1-\gamma_5)b\bar{\ell}\sigma^{\mu\nu}(1-\gamma_5)\bar{\nu}\ell}_{\rm NP}\Big]$$

new tensorial coupling: $\varepsilon_T^\ell=0$ ($\ell=e,\mu$) while $\varepsilon_T^\tau \equiv \varepsilon_T \neq 0$

Differential branching ratio in charmed mesons

$$\frac{d\Gamma}{dq^2}(B\to M_c\ell\bar{\nu}_\ell) = C(q^2)\left[\left.\frac{d\tilde{\Gamma}}{dq^2}\right|_{SM} + \left.\frac{d\tilde{\Gamma}}{dq^2}\right|_{NP} + \left.\frac{d\tilde{\Gamma}}{dq^2}\right|_{INT}\right]$$

$$C(q^2) = \frac{G_F^2|V_{cb}|^2\lambda^{1/2}(m_B^2, m_{M_c}^2), q^2}{192\pi^3 m_B^3}\left(1-\frac{m_l^2}{q^2}\right)$$

$\propto |\varepsilon_T|^2$

$\mathrm{Re}|\varepsilon_T|$

[see also Tanaka & Watanabe PRD 87 (2013) 034028]

R(D$^{(*)}$) in the Standard Model

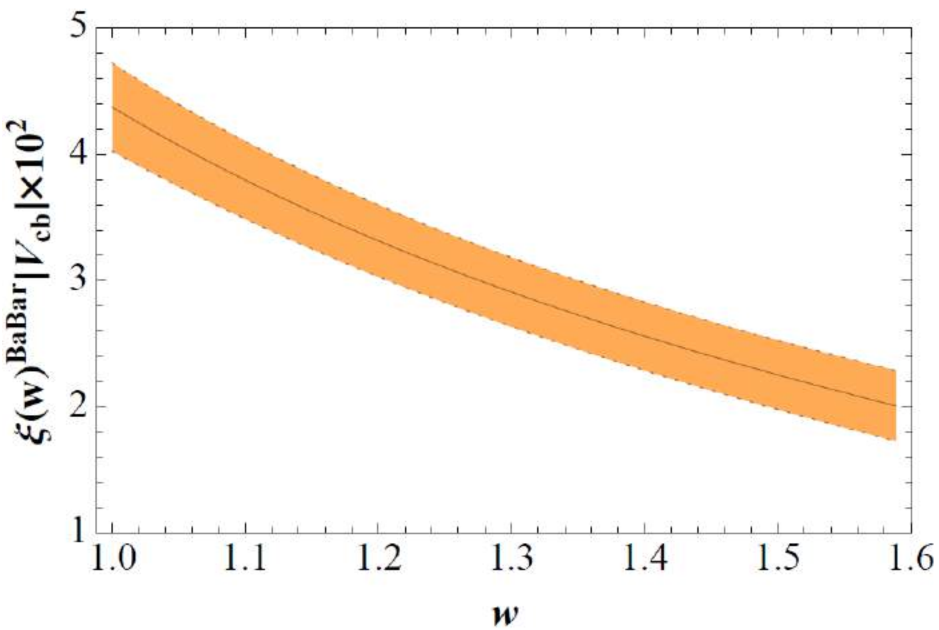
- The decays B -> D τ ν_τ depends on several hadronic form factors, e.g.

$$< D(p\prime)|\bar{c}\gamma_\mu b|B(p) >= F_1(q^2)(p+p\prime)_\mu + \frac{m_B^2 - m_{D^*}^2}{q^2}[F_0(q^2) - F_1(q^2)]q_\mu$$

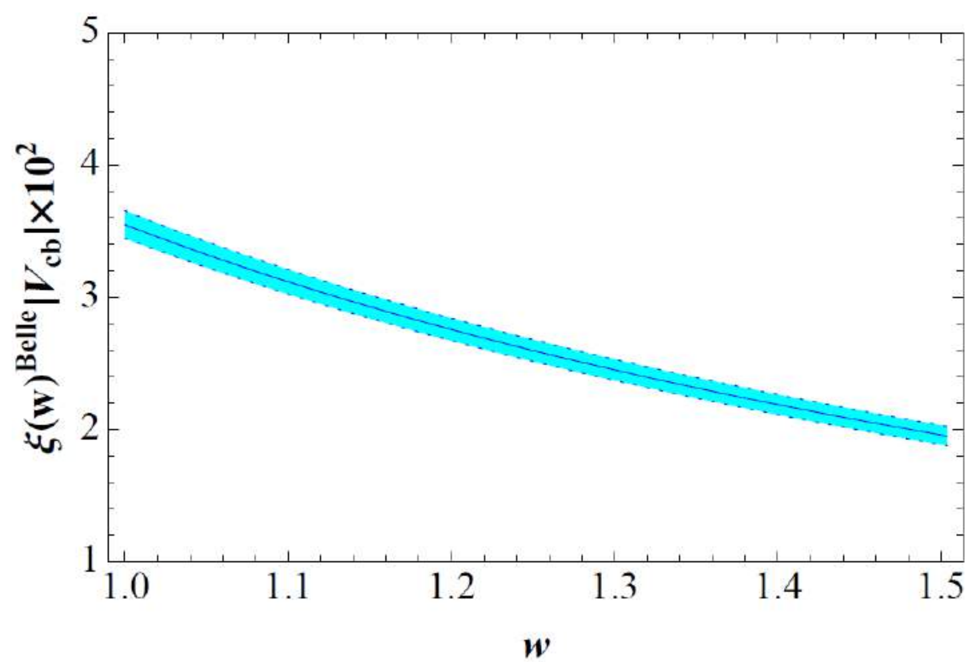
$$< D(p\prime)|\bar{c}\sigma_{\mu\nu}(1-\gamma_5)b|B(p) >= \frac{F_T(q^2)}{m_B+m_D}\epsilon_{\mu\nu\alpha\beta}p\prime^\alpha p^\beta + i\frac{G_T(q^2)}{m_B+m_D}(p_\mu p'_\nu - p_\nu p'_\mu)$$

- They reduce to the Isgur-Wise ξ function in the heavy quark (HQ) limit

Taking into account corrections to HQ limit +
experimental determination of ξ by BABAR (from B -> D μ ν) and Belle (B -> D* μ ν)



R(D)$_{SM}$=0.324 ± 0.022
which deviates @1.5σ from the experiment



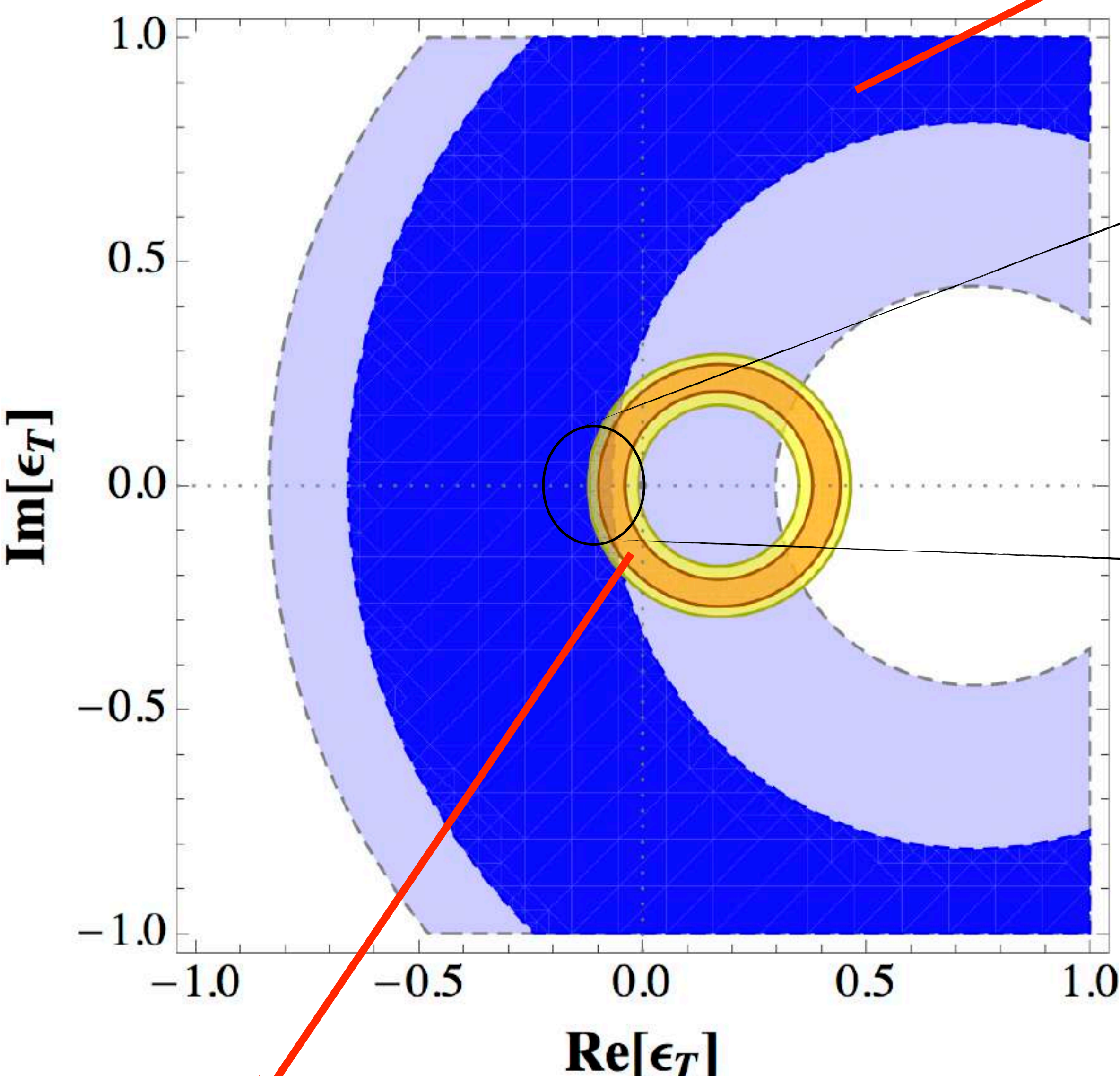
R(D*)$_{SM}$=0.250 ± 0.003
which deviates @2.3σ from the experiment

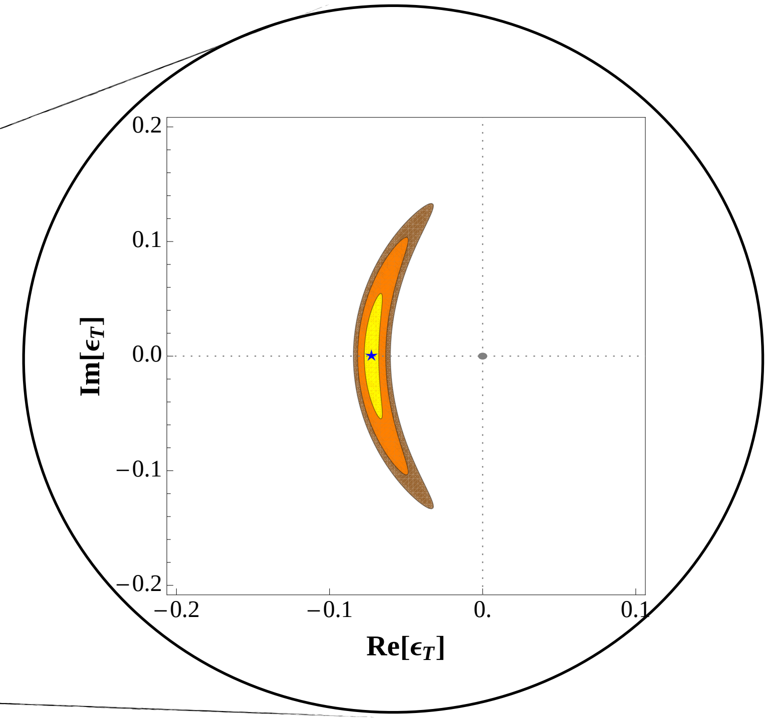
Phenomenology of a new tensor coupling

Could the new effective coupling reproduce both the measures of R(D$^{(*)}$)?

Overlap region

R(D) constraint





$$\boxed{\epsilon_T = |a_T| e^{i\theta} + \epsilon_T^0}$$

$$\mathrm{Re}[\epsilon_T^0] = 0.17, \quad \mathrm{Im}[\epsilon_T^0] = 0$$

$$|a_T| \in [0.24,\ 0.27]$$

$$\theta \in [2.6,\ 3.7] rad$$

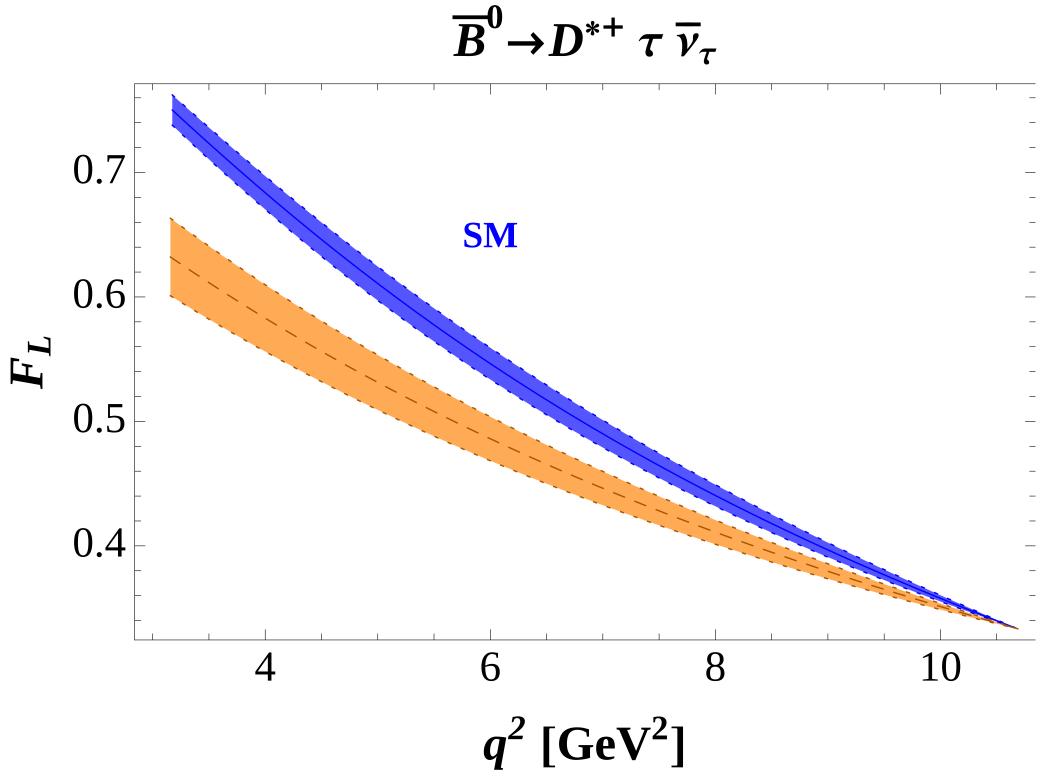
R(D*) constraint

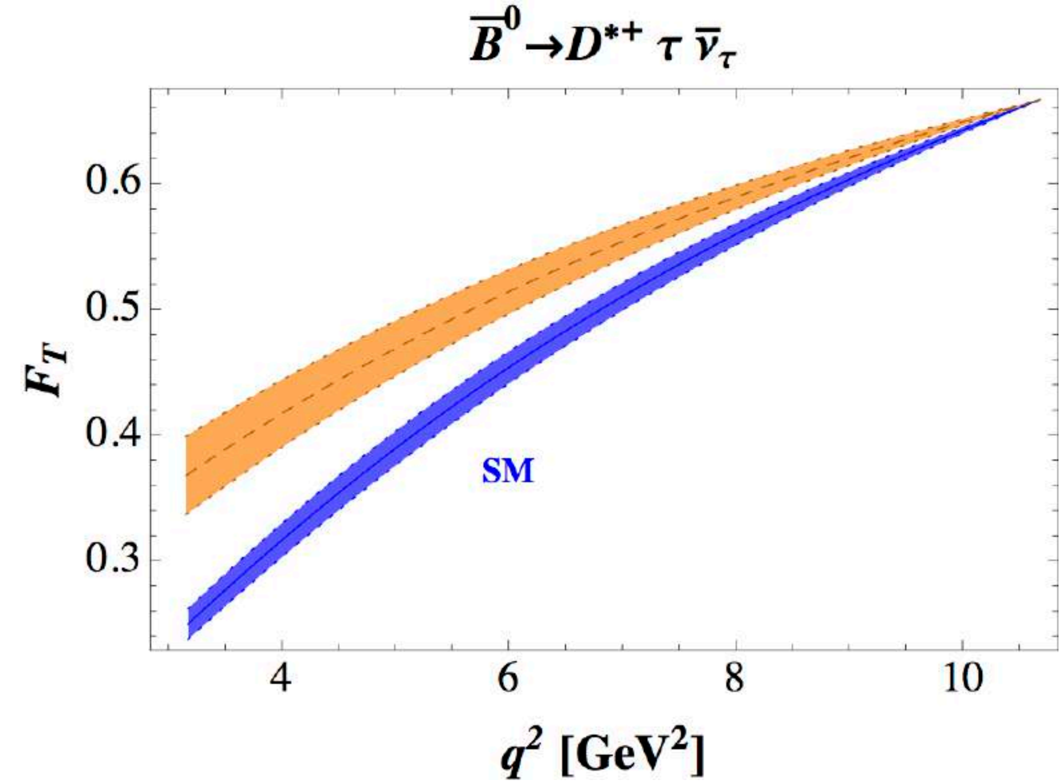
varying ε_T in this range, predictions for several observables have been obtained

Polarization fractions in B -> D* τ ν_τ

$$F_{L,T}(q^2) = \frac{d\Gamma_{L,T}(B \to D^* \tau \bar{\nu}_\tau)}{dq^2} \times \left(\frac{d\Gamma(B \to D^* \tau \bar{\nu}_\tau)}{dq^2} \right)^{-1}$$

L=longitudinal
T=transverse





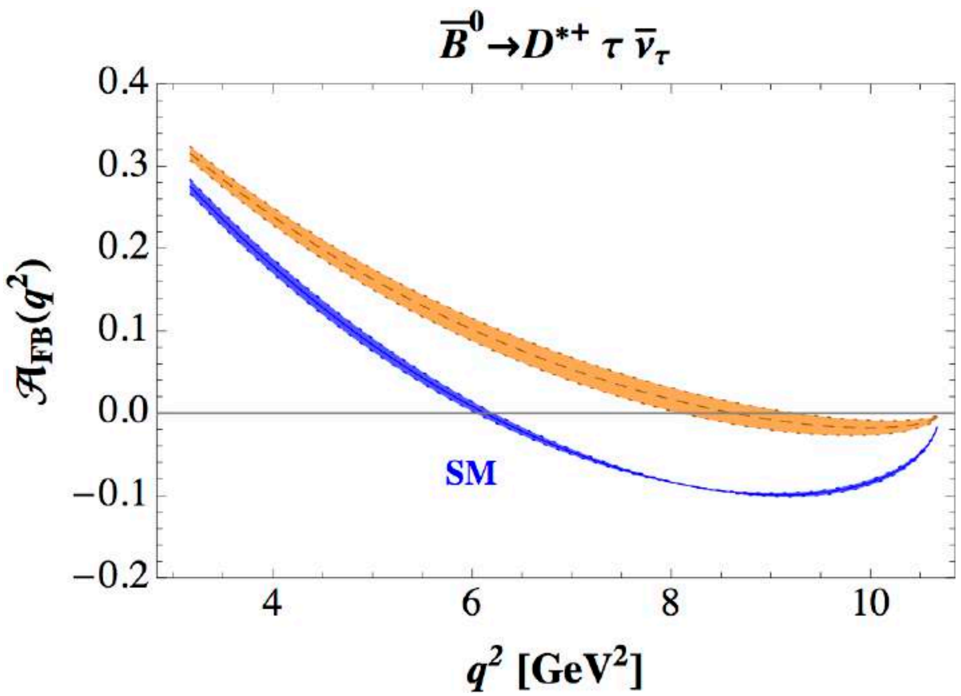
- SM uncertainties depend on $1/m_Q$ corrections + experimental errors on the ξ's parameters fitted by Belle Collaboration
- NP uncertainties include the range of variability of the new coupling

1. @small q^2 -> F_L dominant in SM
2. @ q^2~6 GeV^2 F_L~F_T in the NP scenario

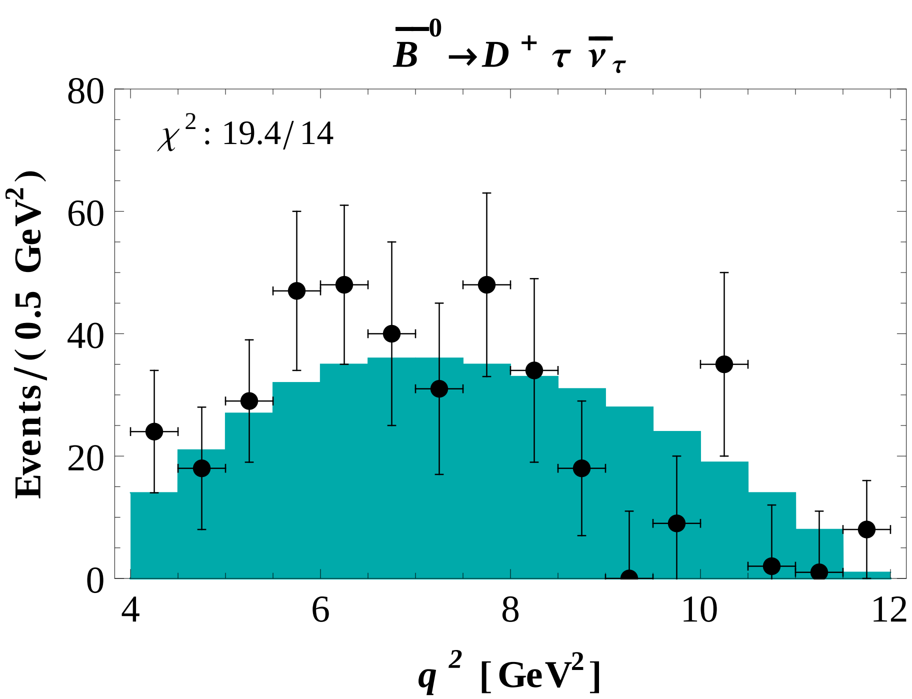
Forward-backward asymmetry and differential BR

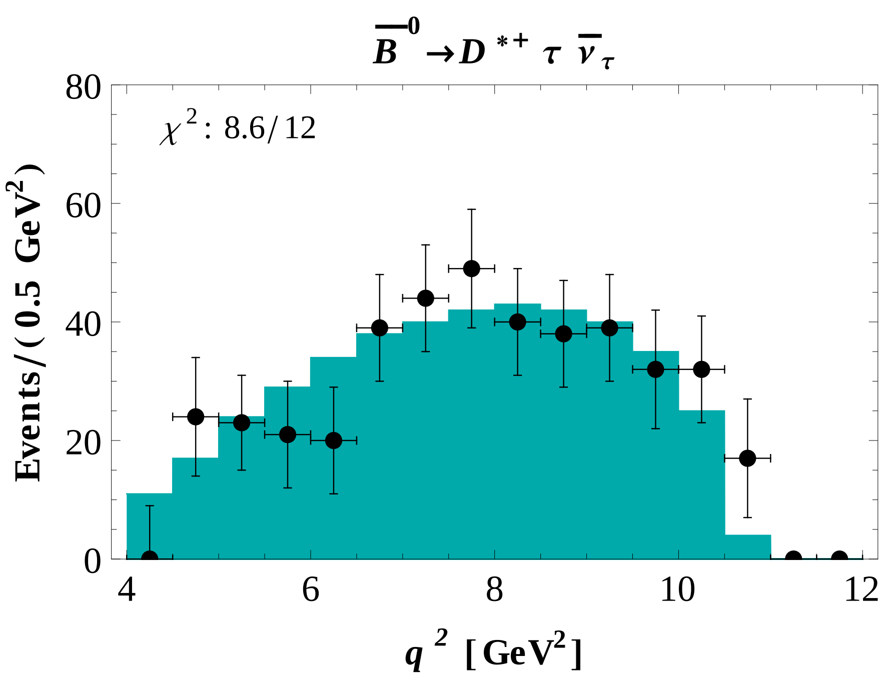
$$\mathcal{A}_{FB}(q^2) = \frac{\int_0^1 d\cos\theta_\ell \frac{d\Gamma}{dq^2\, d\cos\theta_\ell} - \int_{-1}^0 d\cos\theta_\ell \frac{d\Gamma}{dq^2\, d\cos\theta_\ell}}{\frac{d\Gamma}{dq^2}}$$

θ_ℓ= angle between the charged lepton and the D* in the lepton pair rest frame



1. SM predicts a zero @ $q^2 \sim 6.15$ GeV^2
2. in NP scenario the zero is shifted to $q^2 \in [8, 9]$ GeV^2





BABAR differential q^2 decay distributions do not show a significant deviation with respect to SM

[see also BABAR: PRD 88 (2013) 072012]

Predictions for D** channels

D** : excited positive-parity charmed mesons

The semileptonic B decays to these channels could confirm NP physics scenario like the one proposed here.

- These states can be collected into two doublets

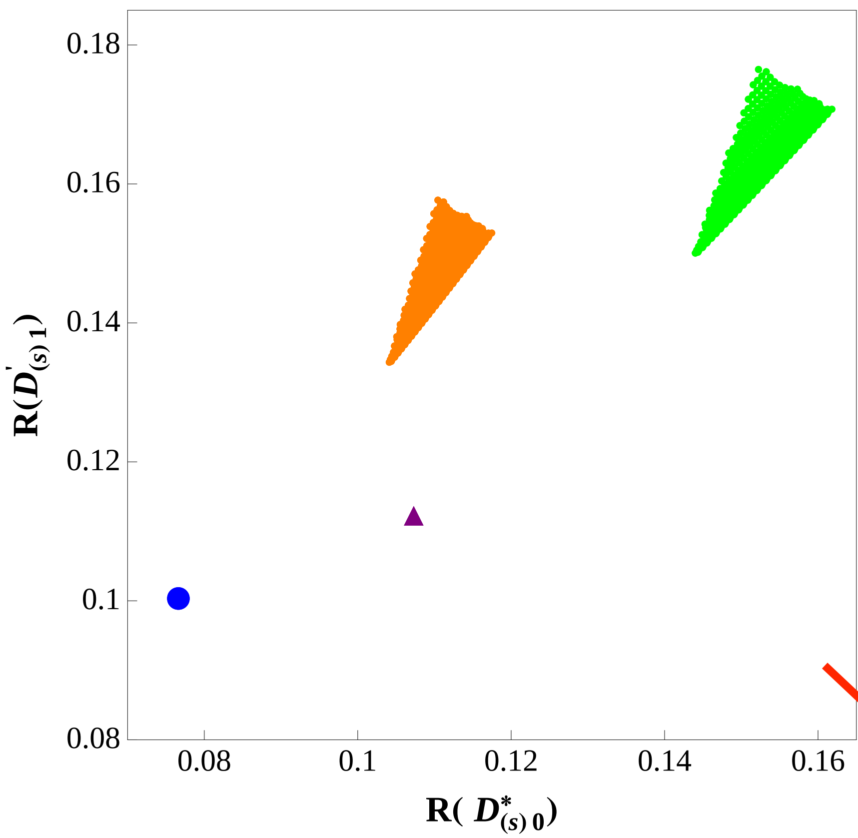
$$(D^*_{(s),0},\, D'_{(s),1}) \;\; \to J^P = (0^+,\, 1^+)$$
$$(D'_{(s),1},\, D^*_{(s),2}) \;\; \to J^P = (1^+,\, 2^+)$$

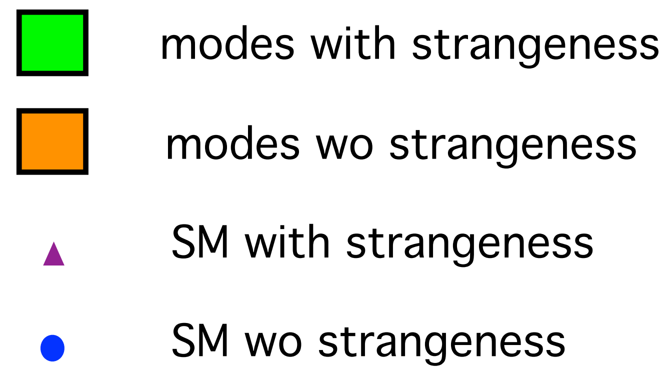
- In the HQ limit the form factors of B ->D** decays can be parameterized via a single IW function

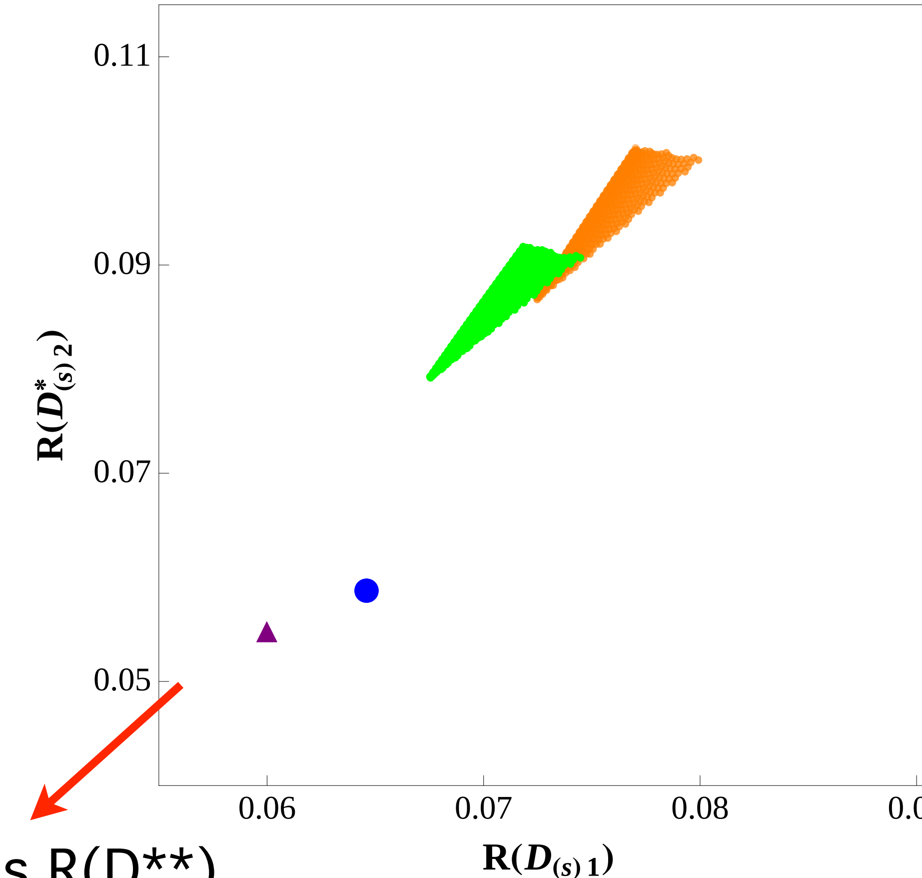
$$B \;\to\; (D^*_{(s),0},\, D'_{(s),1}) \longrightarrow \tau_{1/2}$$
$$B \;\to\; (D'_{(s),1},\, D^*_{(s),2}) \longrightarrow \tau_{3/2}$$

- We explore the same observables seen for the B -> $D^{(*)}$ channel looking for interesting signatures : R(D**) and A_{FB}

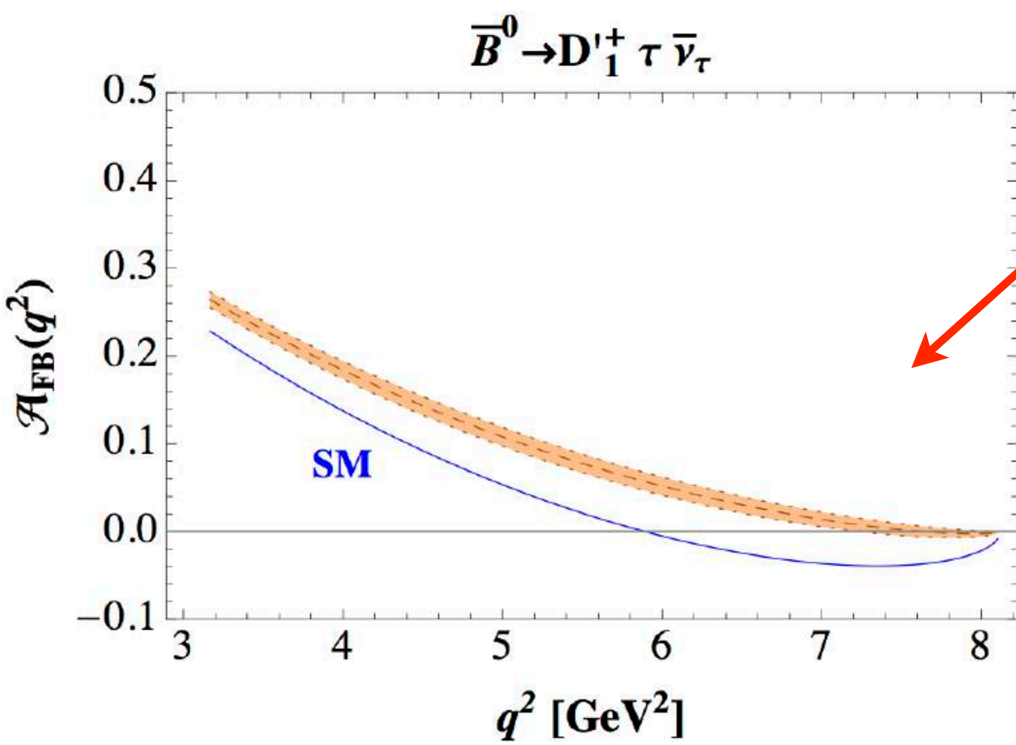
Predictions for D** channels



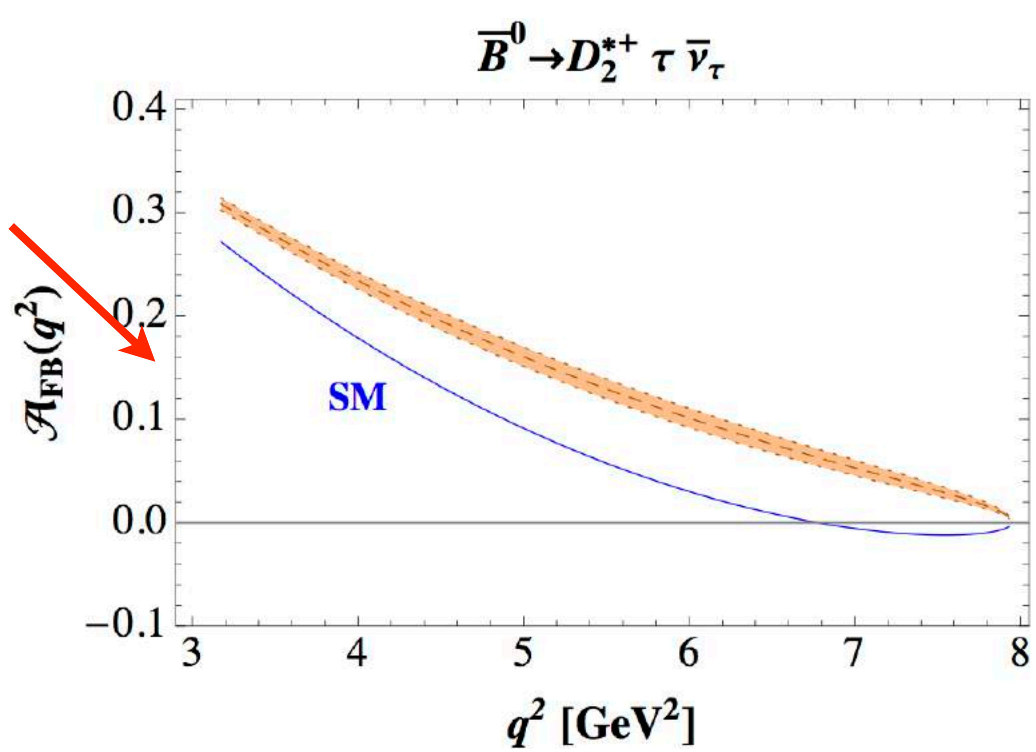




1) sizable increase in the ratios R(D**)
2) mild hadronic uncertainties



shift of the zeros



B $\to$ K* $\ell^+\ell^-$

[P.B., P. Colangelo and F. De Fazio BARI-TH/2014-687]

b $\to$ s ℓ^+ ℓ^- effective hamiltonian:

$$\mathcal{H}^{\text{eff}} = -4\frac{G_F}{\sqrt{2}}V_{tb}V_{ts}^*\Big\{C_1\mathcal{O}_1 + C_2\mathcal{O}_2 + \sum_{i=3,\dots,6} C_i\mathcal{O}_i + \sum_{i=7,\dots,10,P,S} \underbrace{[C_i\mathcal{O}_i + C_i'\mathcal{O}_i']}_{\text{differ for chirality}}\Big\}$$

$$O_7 = \frac{e}{16\pi^2}m_b(\bar{s}_{L\alpha}\sigma^{\mu\nu}b_{R\alpha})F_{\mu\nu} \qquad O_7' = \frac{e}{16\pi^2}m_b(\bar{s}_{R\alpha}\sigma^{\mu\nu}b_{L\alpha})F_{\mu\nu}$$

$$O_8 = \frac{g_s}{16\pi^2}m_b\left[\bar{s}_{L\alpha}\sigma^{\mu\nu}\left(\frac{\lambda^a}{2}\right)_{\alpha\beta}b_{R\beta}\right]G^a_{\mu\nu} \qquad O_8' = \frac{g_s}{16\pi^2}m_b\left[\bar{s}_{R\alpha}\sigma^{\mu\nu}\left(\frac{\lambda^a}{2}\right)_{\alpha\beta}b_{L\beta}\right]G^a_{\mu\nu}$$

$$O_9 = \frac{e^2}{16\pi^2}(\bar{s}_{L\alpha}\gamma^\mu b_{L\alpha})\,\bar{\ell}\gamma_\mu\ell \qquad O_9' = \frac{e^2}{16\pi^2}(\bar{s}_{R\alpha}\gamma^\mu b_{R\alpha})\,\bar{\ell}\gamma_\mu\ell$$

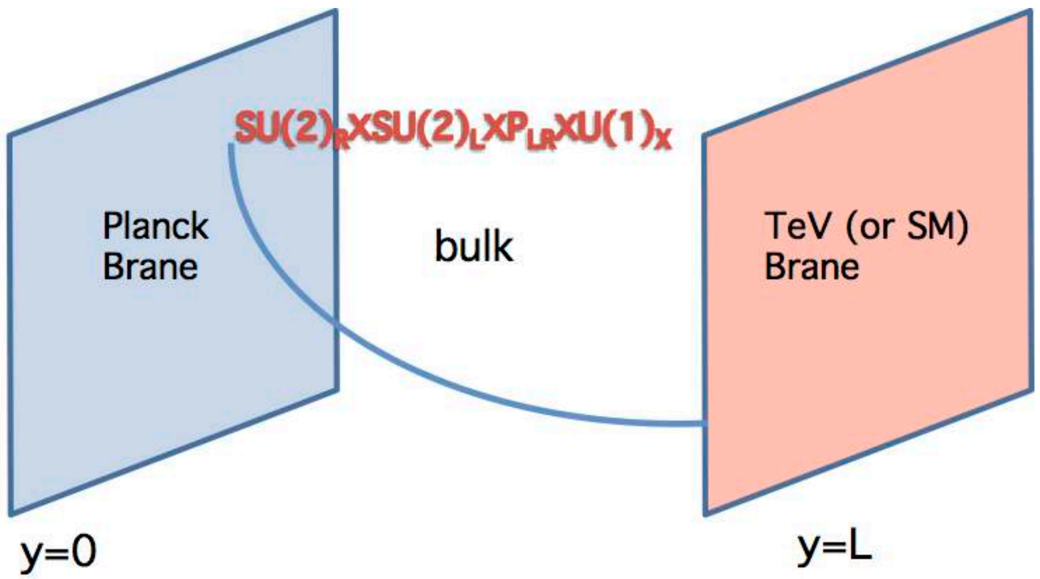
$$O_{10} = \frac{e^2}{16\pi^2}(\bar{s}_{L\alpha}\gamma^\mu b_{L\alpha})\,\bar{\ell}\gamma_\mu\gamma_5\ell \qquad O_{10}' = \frac{e^2}{16\pi^2}(\bar{s}_{R\alpha}\gamma^\mu b_{R\alpha})\,\bar{\ell}\gamma_\mu\gamma_5\ell$$

- Hadronic uncertainties can be softened by using optimized observables
[definitions in Altmannshofer et al. JHEP 0901 (2009) 019 - Descotes-Genon et al. JHEP 1301 (2013) 048]

- New oustanding results from LHCb Coll. [JHEP 1308 131 - PRL 111 (2013) 191801]
$\to$ a huge set of optimized observables P'_i measured (Matias talk)

- Tensions with respect to SM in P'_5 @3.7σ in one q^2 bin $\to$ a signal of New Physics?

Randall-Sundrum model with custodial symmetry

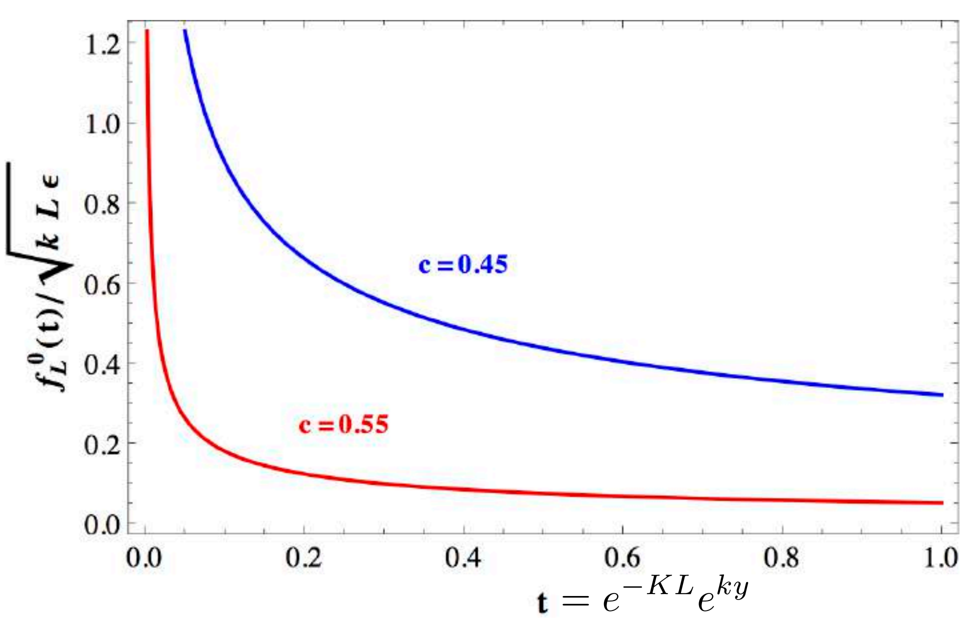


[Randall & Sundrum PRL 83, 3370]

$$ds^2 = e^{-2k|y|}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2$$

Planck scale

- All the gauge fields and the fermions are allowed to propagate in the bulk, Higgs field localized on the TeV brane -> the EWSB scale depends on a geometric factor, only the Planck scale is physical
- Boundary conditions (Neumann vs Dirichlet) select the zero modes
- Gauge group: $SU(3)_C \times SU(2)_R \times SU(2)_L \times P_{LR} \times U(1)_X$ -> flavor structure not trivial: new gauge bosons mediate FCNC at three level (to take under control !)
- $Zb\bar{b}$ coupling and the T parameter ‘custodially protected’
- Several theoretical motivations

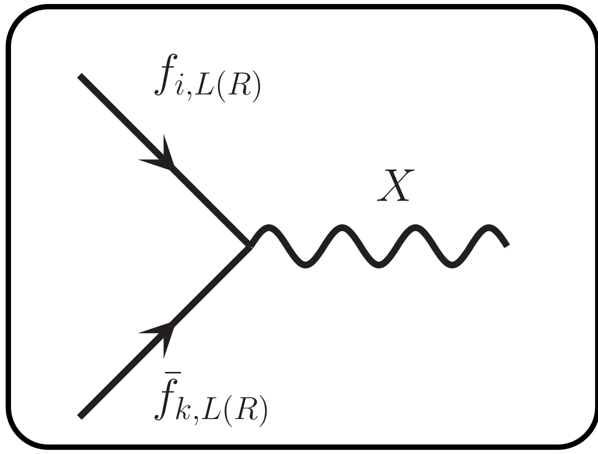


<u>fermion profile:</u> $f^{(0)}_{L,R}(y) = \sqrt{\frac{(1\mp 2c)kL}{e^{(1\mp 2c)KL} - 1}}\, e^{(2\mp c)ky}$

The c_i parameters determine the localization of the fermion along the extra dim. -> they must be constrained by EW precision data.

[see Casagrande et al. JHEP 0810 094; JHEP 1009 014]

RSc contribution to B $\longrightarrow$ K* $\ell^+\ell^-$



$X \;=\; Z,\, Z_H,\, Z'$ and $A^{(1)}$

$$\Delta C_9 = \left[\frac{\Delta Y_s}{\sin^2(\theta_W)} - 4\Delta Z_s\right]$$

[Blanke et al. JHEP 0903 001; JHEP 0903 108; JHEP 0909 064; JHEP 1208 038]

$$\Delta C_{10} = -\frac{\Delta Y_s}{\sin^2(\theta_W)}$$

+ similar expression for $\Delta C'_9$ e $\Delta C'_{10}$.

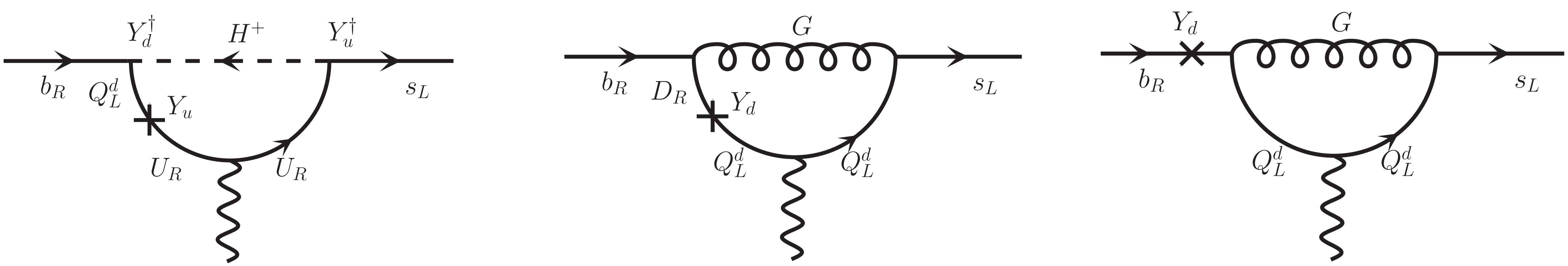
with

$$\Delta Y_s = -\frac{1}{V_{tb}V_{ts}^*}\sum_X \frac{\Delta_L^{\ell\ell}(X) - \Delta_R^{\ell\ell}(X)}{4M_X^2 g_{SM}^2}\Delta_L^{bs}(X)$$

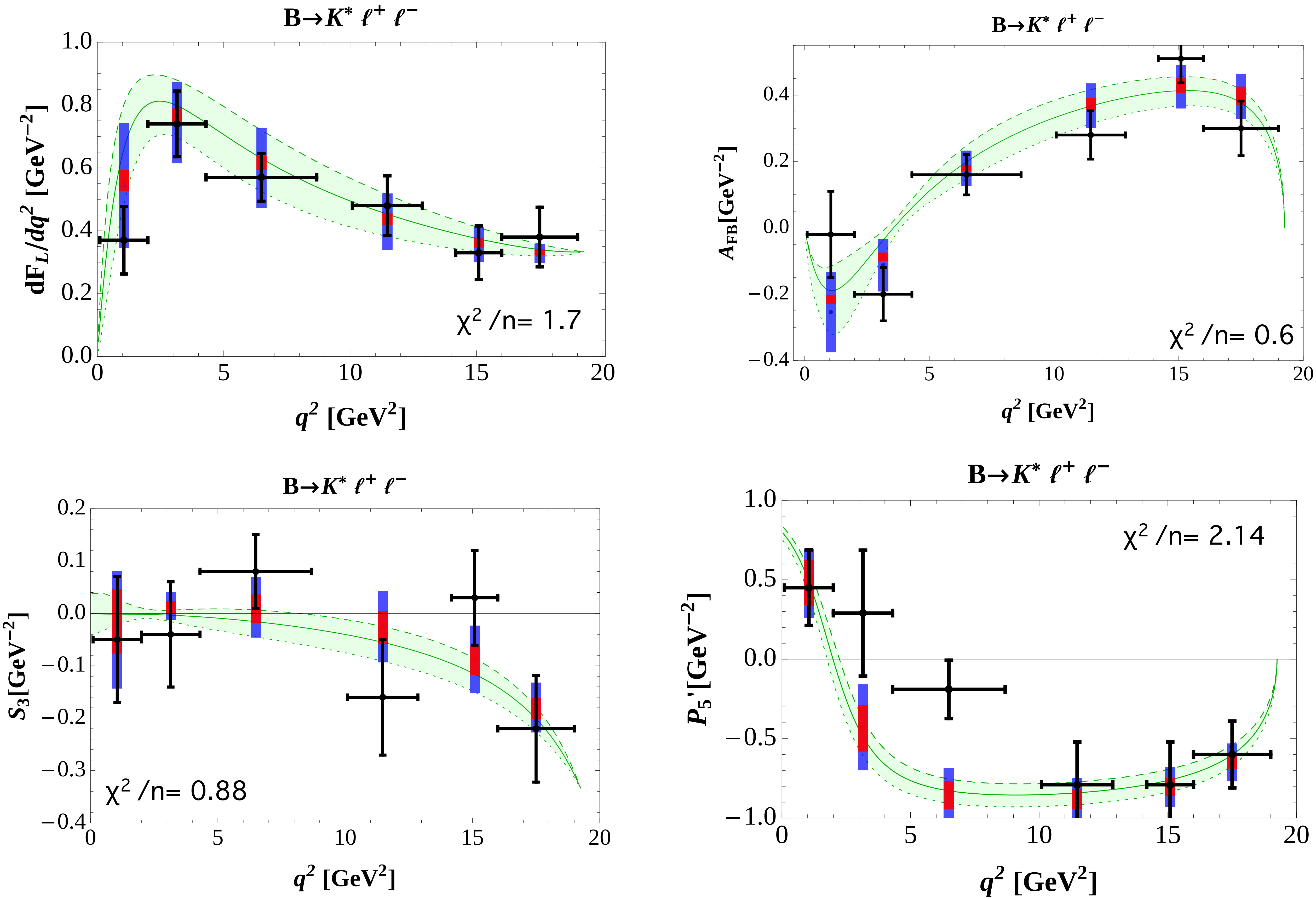
&

$$\Delta Z_s = \frac{1}{V_{tb}V_{ts}^*}\sum_X \frac{\Delta_R^{\ell\ell}(X)}{8M_X^2 g_{SM}^2 \sin^2(\theta_W)}\Delta_L^{bs}(X)$$

- Main contributions to $\Delta C^{(\prime)}_7$ coefficient:



RSc predictions facing LHCb data



Conclusions

1. Flavor physics in exciting time since new data are /will be available with the LHC

2. Most tensions with SM have been softened while others still remain or have been discovered and puzzle us

3. Semileptonic decays with tau in the final states can be used to test some new effective structures $\longrightarrow$ interesting signatures for a new tensorial coupling (LHCb is planning to do measurements)

4. B $\longrightarrow$ K* $\ell^+\ell^-$ puzzle still survives in RSc scenario.

THANKS