Charm loop contributions in $B \to K^* \mu^+ \mu^-$ decays.

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the good, the bad and the ugly

$$H_V(\lambda) = -i\,N\left\{C_9\tilde{V}_{L\lambda} + C_9'\tilde{V}_{R\lambda} + \frac{m_B^2}{q^2}\left[\frac{2\,\hat{m}_b}{m_B}(C_7\tilde{T}_{L\lambda} + C_7'\tilde{T}_{R\lambda}) - 16\pi^2 h_\lambda\right]\right\}$$

$$H_A(\lambda) = -i\,N(C_{10}\tilde{V}_{L\lambda} + C_{10}'\tilde{V}_{R\lambda}),$$

$$V_\pm(q^2) = \frac{1}{2}\left[\left(1+\frac{m_V}{m_B}\right)A_1(q^2) \mp \frac{\lambda^{1/2}}{m_B(m_B+m_V)}V(q^2)\right],$$

$$V_0(q^2) = \frac{1}{2m_V\lambda^{1/2}(m_B+m_V)}\left[(m_B+m_V)^2(m_B^2-q^2-m_V^2)A_1(q^2) - \lambda A_2(q^2)\right]$$

$$T_\pm(q^2) = \frac{m_B^2-m_V^2}{2m_B^2}T_2(q^2) \mp \frac{\lambda^{1/2}}{2m_B^2}T_1(q^2),$$

$$T_0(q^2) = \frac{m_B}{2\,m_V\lambda^{1/2}}\left[(m_B^2+3m_V^2-q^2)T_2(q^2) - \frac{\lambda}{(m_B^2-m_V^2)}T_3(q^2)\right],$$

$$S(q^2) = A_0(q^2),$$

LCSR at large recoil (low q^2) [hep-ph/0412079 and arXiv:1503.05534]
Lattice at small recoil (high q^2) [arXiv:1501.00267]

$$h_\lambda = h_\lambda^{(0)} + h_\lambda^{(1)}q^2 + h_\lambda^{(2)}q^4,\ (\lambda = 0, \pm)$$

Caveat: a ΔC_9 or ΔC_7 would have a similar effect on the observables.

the angular observables

$$P_1 = -\frac{2\left(\Re\left[\left(C_{10}V_+\right)\left(C_{10}V_-\right)^*\right] + \Re\left[\left(\frac{m_B^2}{q^2}\left(16\pi^2 h_+ - 2\frac{m_b}{m_B}C_7T_+\right) - C_9V_+\right)\left(\frac{m_B^2}{q^2}\left(16\pi^2 h_- - 2\frac{m_b}{m_B}C_7T_-\right) - C_9V_-\right)^*\right]\right)}{\left(1 - 4\frac{m_l^2}{q^2}\right)\left(\left|C_{10}V_-\right|^2 + \left|C_{10}V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16h_+\pi^2 - 2\frac{m_b}{m_B}C_7T_+\right) - C_9V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16h_-\pi^2 - 2\frac{m_b}{m_B}C_7T_-\right) - C_9V_-\right|^2\right)}$$

$$P_2 = \frac{\Re\left[\left(\frac{m_B^2}{q^2}\left(16\pi^2 h_+ - 2\frac{m_b}{m_B}C_7T_+\right) - C_9V_+\right)\left(-C_{10}'V_-\right)^* + \left(\frac{m_B^2}{q^2}\left(16\pi^2 h_- - 2\frac{m_b}{m_B}C_7T_-\right) - C_9V_-\right)\left(C_{10}V_-\right)^*\right]}{\sqrt{1 - 4\frac{m_l^2}{q^2}}\left(\left|C_{10}V_-\right|^2 + \left|C_{10}V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16h_+\pi^2 - 2\frac{m_b}{m_B}C_7T_+\right) - C_9V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16h_-\pi^2 - 2\frac{m_b}{m_B}C_7T_-\right) - C_9V_-\right|^2\right)}$$

$$P_3 = -\frac{\Im\left[\left(C_{10}V_+\right)\left(C_{10}V_-\right)^*\right] + \Im\left[\left(\frac{m_B^2}{q^2}\left(16\pi^2 h_+ - 2\frac{m_b}{m_B}C_7T_+\right) - C_9V_+\right)\left(\frac{m_B^2}{q^2}\left(16\pi^2 h_- - 2\frac{m_b}{m_B}C_7T_-\right) - C_9V_-\right)^*\right]}{\left|C_{10}V_-\right|^2 + \left|C_{10}V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16h_+\pi^2 - 2\frac{m_b}{m_B}C_7T_+\right) - C_9V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16h_-\pi^2 - 2\frac{m_b}{m_B}C_7T_-\right) - C_9V_-\right|^2}$$

$$P_4' = \frac{\Re\left[C_{10}(V_- + V_+)(C_{10}\tilde{V}_0)^*\right] + \Re\left[\left(\frac{m_B^2}{q^2}\left(16\pi^2(h_- + h_+) - 2\frac{m_b}{m_B}C_7(T_+T_+)\right) - C_9(V_- + V_+)\right)\left(\frac{m_B^2}{q^2}\left(16\pi^2 h_0 - 2\frac{m_b}{m_B}C_7\tilde{T}_0\right) - C_9\tilde{V}_0\right)^*\right]}{\sqrt{\left(\left|C_{10}\tilde{V}_0\right|^2 + \left|\frac{m_B^2}{q^2}\left(16\pi^2 h_0 - 2\frac{m_b}{m_B}C_7\tilde{T}_0\right) - C_9\tilde{V}_0\right|^2\right)\left(\left|C_{10}V_-\right|^2 + \left|C_{10}V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16\pi^2 h_+ - 2\frac{m_b}{m_B}C_7T_+\right) - C_9V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16\pi^2 h_- - 2\frac{m_b}{m_B}C_7T_-\right) - C_9V_-\right|^2\right)}}$$

$$P_5' = -\frac{\Re\left[\left(16\pi^2\frac{m_B^2}{q^2}(h_- - h_+) - 2\frac{m_bm_B}{q^2}C_7(T_- - T_+) - C_9(V_- - V_+)\right)\left(C_{10}\tilde{V}_0\right)^*\right] + \Re\left[C_{10}(V_- - V_+)\left(16\pi^2\frac{m_B^2}{q^2}h_0 - 2\frac{m_bm_B}{q^2}C_7\tilde{T}_0 - C_9\tilde{V}_0\right)^*\right]}{\sqrt{\left(1 - \frac{4m_l^2}{q^2}\right)\left(\left|C_{10}\tilde{V}_0\right|^2 + \left|\frac{m_B^2}{q^2}\left(16\pi^2 h_0 - 2\frac{m_b}{m_B}C_7\tilde{T}_0\right) - C_9\tilde{V}_0\right|^2\right)\left(\left|C_{10}V_-\right|^2 + \left|C_{10}V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16\pi^2 h_+ - 2\frac{m_b}{m_B}C_7T_+\right) - C_9V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16\pi^2 h_- - 2\frac{m_b}{m_B}C_7T_-\right) - C_9V_-\right|^2\right)}}$$

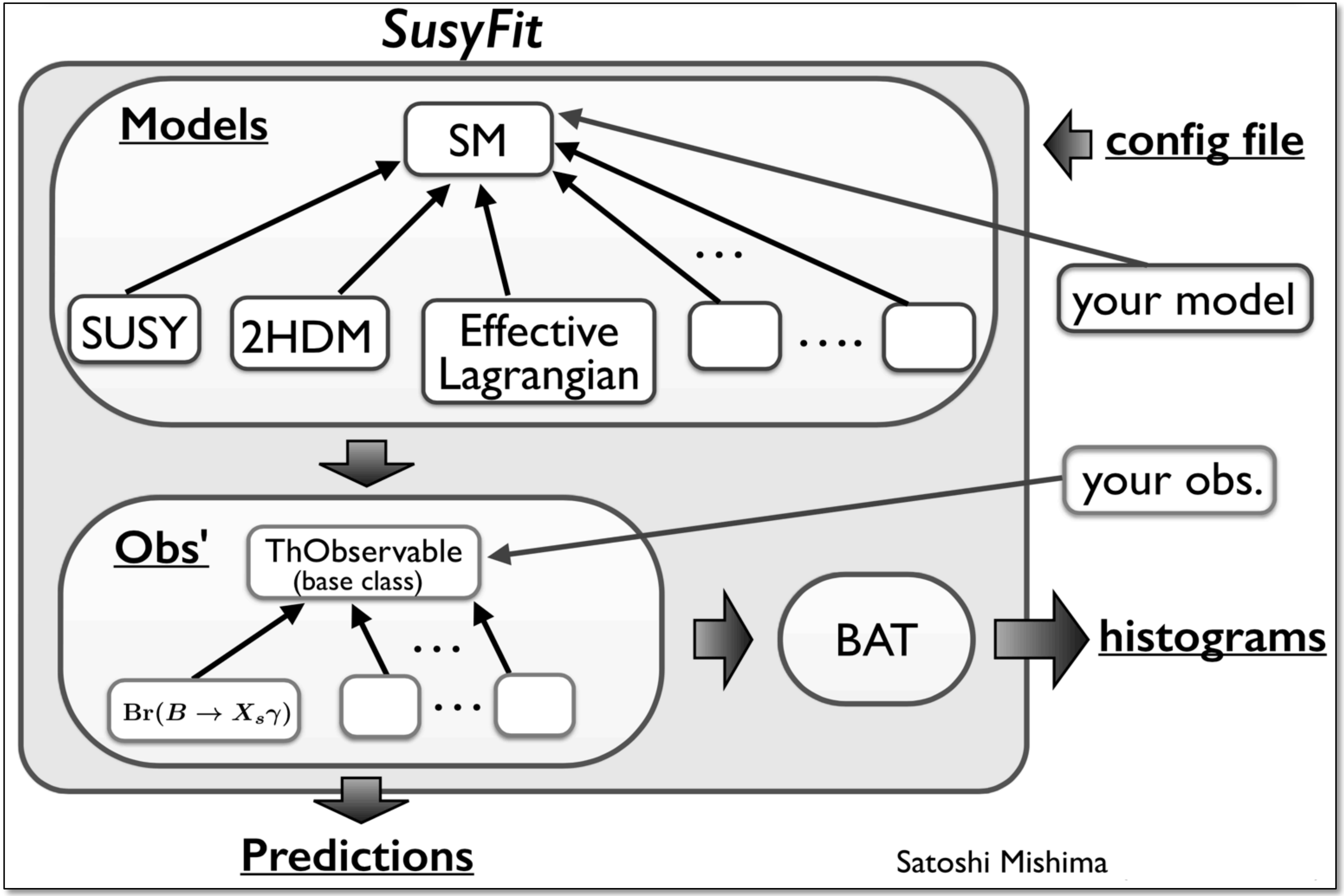
$$P_6' = -\frac{\Im\left[\left(16\pi^2\frac{m_B^2}{q^2}(h_- - h_+) - 2\frac{m_bm_B}{q^2}C_7(T_- - T_+) - C_9(V_- - V_+)\right)\left(C_{10}\tilde{V}_0\right)^*\right] + \Im\left[C_{10}(V_- - V_+)\left(16\pi^2\frac{m_B^2}{q^2}h_0 - 2\frac{m_bm_B}{q^2}C_7\tilde{T}_0 - C_9\tilde{V}_0\right)^*\right]}{\sqrt{\left(1 - \frac{4m_l^2}{q^2}\right)\left(\left|C_{10}\tilde{V}_0\right|^2 + \left|\frac{m_B^2}{q^2}\left(16\pi^2 h_0 - 2\frac{m_b}{m_B}C_7\tilde{T}_0\right) - C_9\tilde{V}_0\right|^2\right)\left(\left|C_{10}V_-\right|^2 + \left|C_{10}V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16\pi^2 h_+ - 2\frac{m_b}{m_B}C_7T_+\right) - C_9V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16\pi^2 h_- - 2\frac{m_b}{m_B}C_7T_-\right) - C_9V_-\right|^2\right)}}$$

$$P_8' = \frac{\Im\left[C_{10}(V_- - V_+)(C_{10}\tilde{V}_0)^*\right] + \Im\left[\left(\frac{m_B^2}{q^2}\left(16\pi^2(h_- - h_+) - 2\frac{m_b}{m_B}C_7(T_-T_+)\right) - C_9(V_- - V_+)\right)\left(\frac{m_B^2}{q^2}\left(16\pi^2 h_0 - 2\frac{m_b}{m_B}C_7\tilde{T}_0\right) - C_9\tilde{V}_0\right)^*\right]}{\sqrt{\left(\left|C_{10}\tilde{V}_0\right|^2 + \left|\frac{m_B^2}{q^2}\left(16\pi^2 h_0 - 2\frac{m_b}{m_B}C_7\tilde{T}_0\right) - C_9\tilde{V}_0\right|^2\right)\left(\left|C_{10}V_-\right|^2 + \left|C_{10}V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16\pi^2 h_+ - 2\frac{m_b}{m_B}C_7T_+\right) - C_9V_+\right|^2 + \left|\frac{m_B^2}{q^2}\left(16\pi^2 h_- - 2\frac{m_b}{m_B}C_7T_-\right) - C_9V_-\right|^2\right)}}$$

best estimates (but estimates only...)

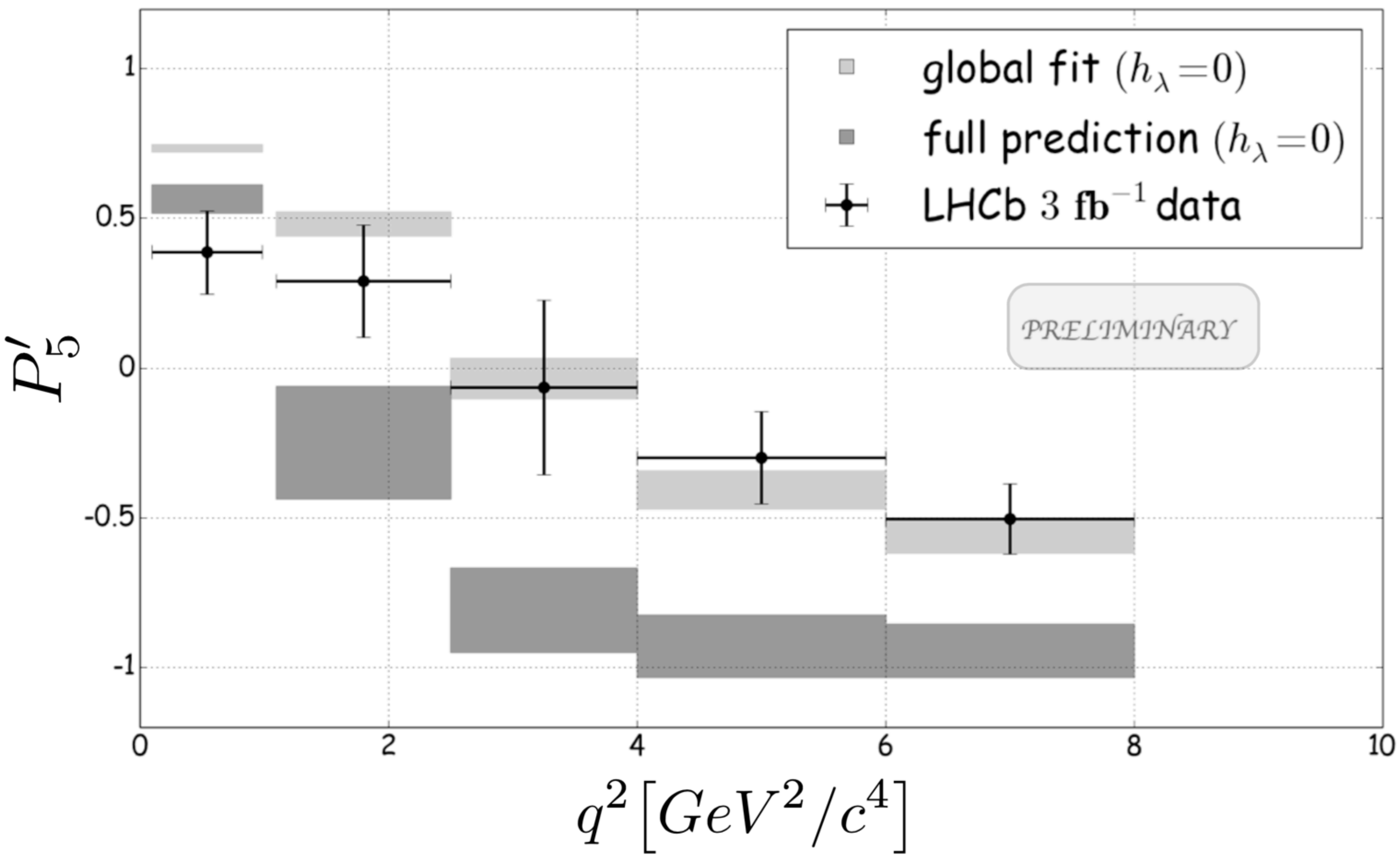
- The weakest link in the analysis is the estimates of the non-factorizable part.
- However, the estimates of the angular observables in the SM depend heavily on the estimate of the non-factorizable part.
- The nonlinear dependence of the angular observables on the hadronic contribution means that the central value *and* the error in the prediction depends on the size of this estimate.
- The *only* theory estimate available in the literature (arXiv:1006:4945) takes into account only a part of the possible contribution (soft gluon contribution)
- Other contributing diagrams can possible bring about corrections to this estimate that is as large or larger than the current estimate depending on the kinematic region one considers.

our weapon of choice



a Bayesian analysis toolkit for electroweak, flavour and Higgs observables
based on BAT (https://www.mppmu.mpg.de/bat/)

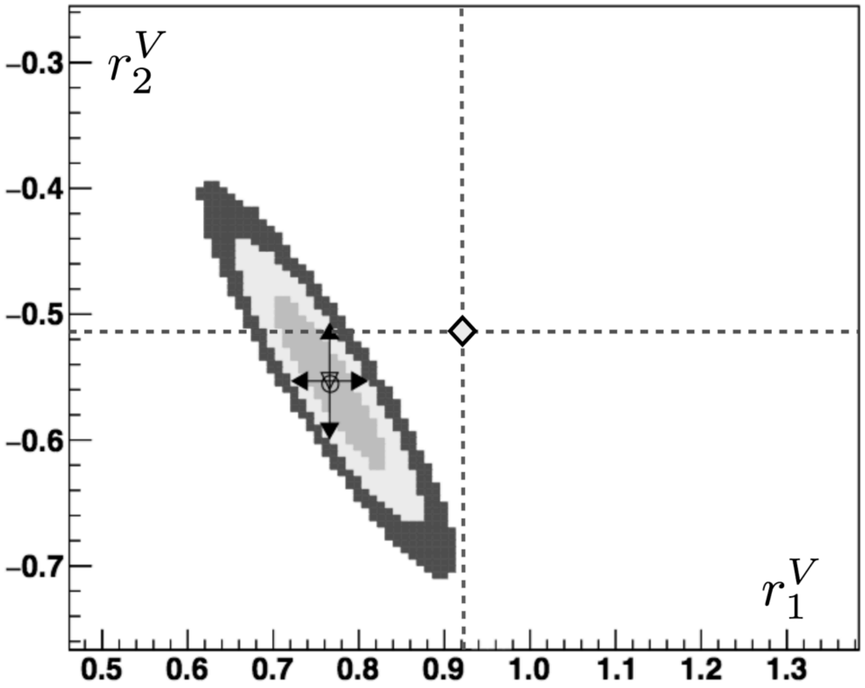
underestimates...

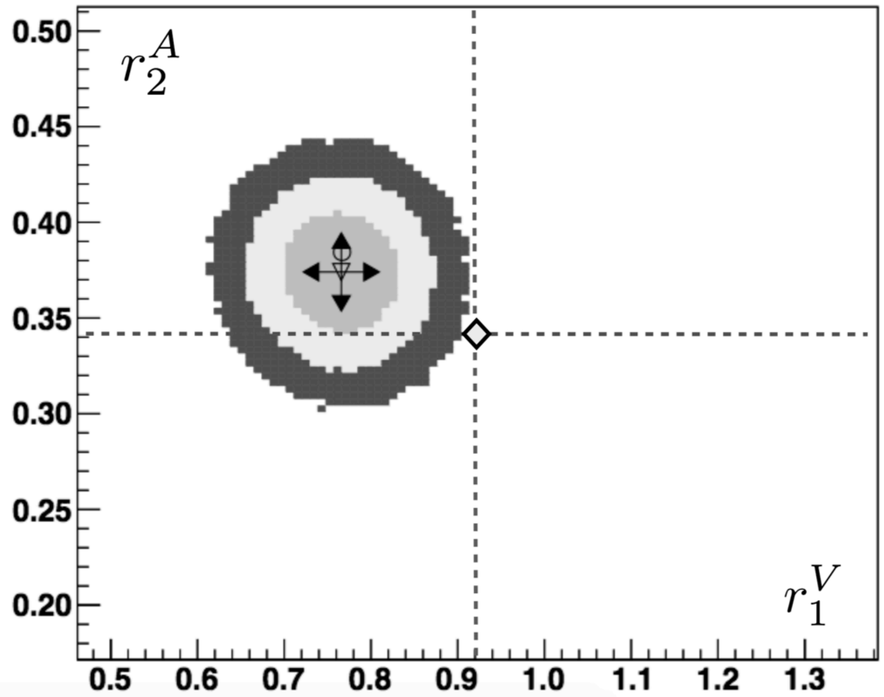


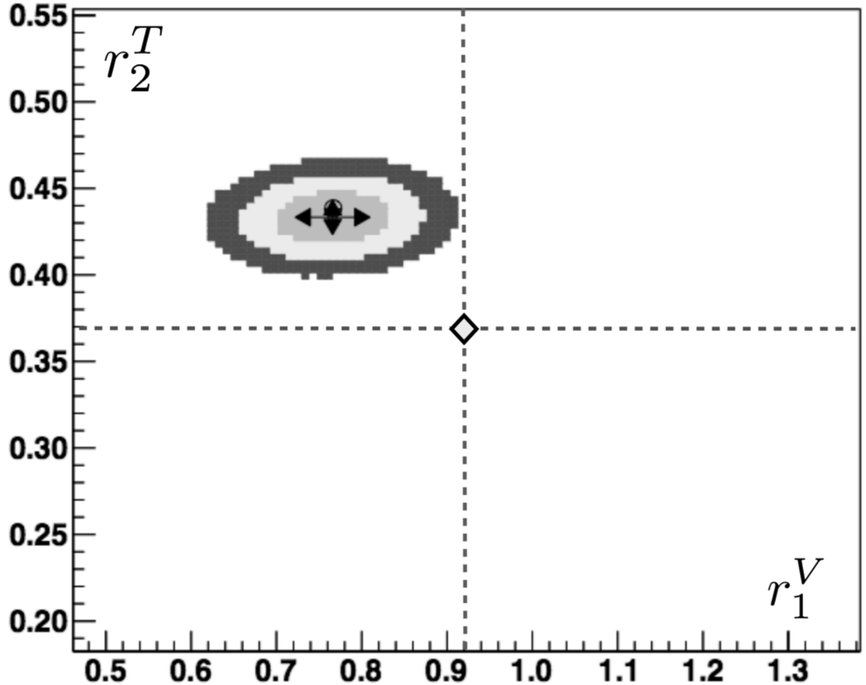
- data blind + underestimated hadronic contribution lead to incorrect estimates of the angular observables
- using data can seemingly lead to "correct" estimates…

however…

underestimates...



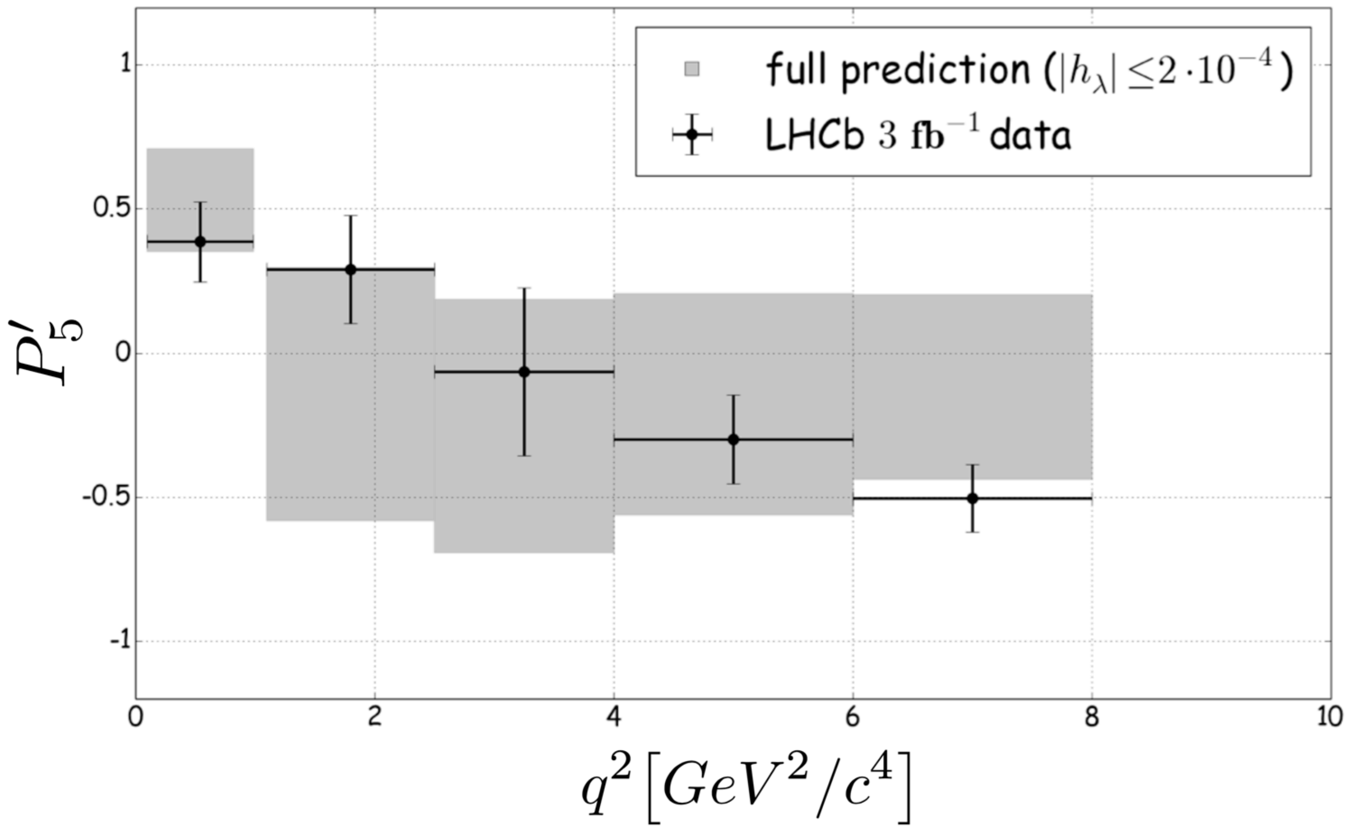




underestimated hadronic contributions can contrain the for factors and move them away from theory estimates.

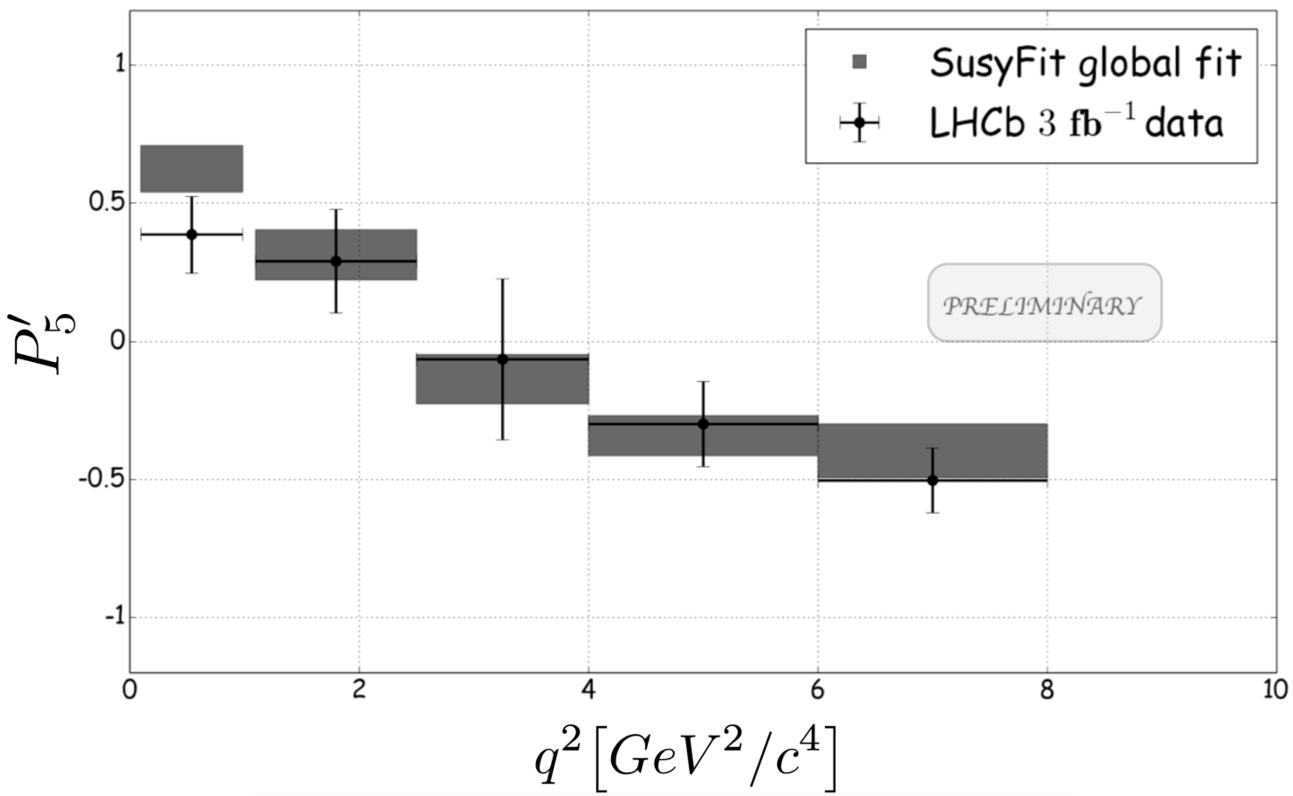
form factor parameterization from Ball and Zwicky (hep-ph/0412079)

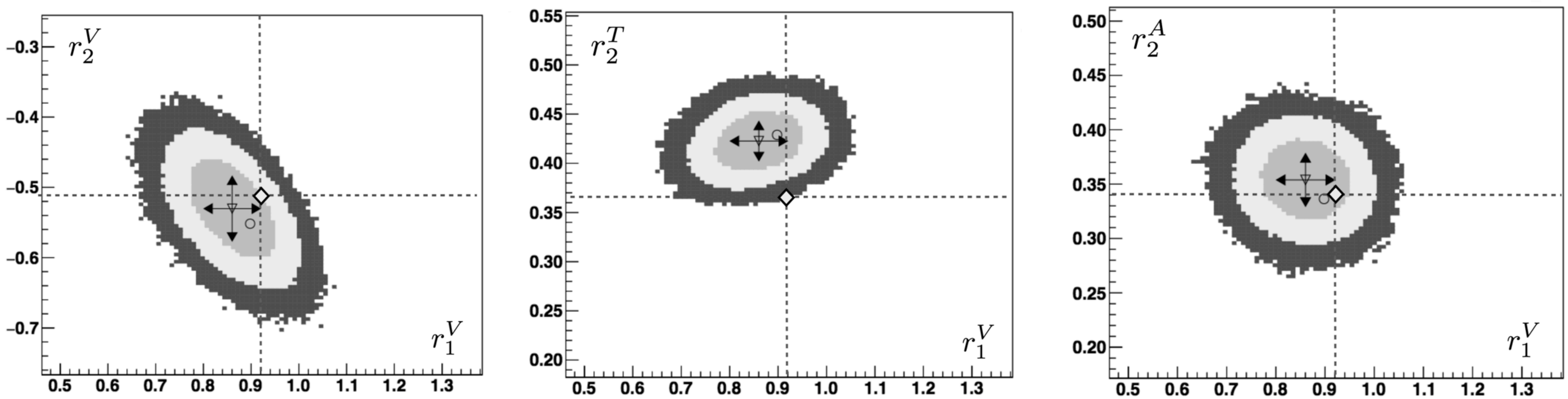
overestimates…



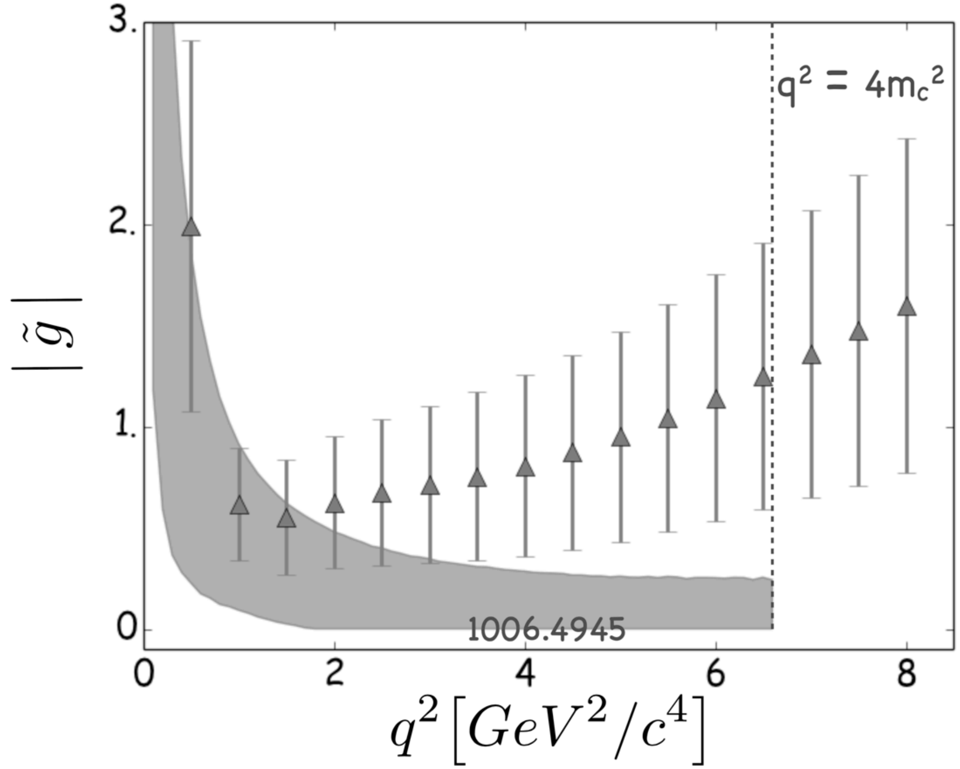
- data-blind estimations of the angular observables with large hadronic contributions can lead to a large shift in both the central values and inflation of errors in the angular observables.

using the data





the question of hadronic contribution



$$\Delta C_9^{(\bar{c}c, B\to K^*, \mathcal{M}_i)}(q^2) = (C_1 + 3C_2)\, g(m_c^2, q^2) + 2C_1 \widetilde{g}^{\,(\bar{c}c, B\to K^*, \mathcal{M}_i)}(q^2)$$

- in the very low q^2 regime the hadronic contributions extracted from data and theory estimates seem to be compatible

- in the region closer to the resonance hadronic contributions extracted from data seem to be larger than theory estimates, as they should be

key ingredients

- we do a complete Bayesian analysis using full experimental data will all available correlations (angular observables measured with 3 fb^{-1} and branching fraction measured with 1 fb^{-1})
- we use $B \to K^* \gamma$ to fix the hadronic contribution at $q^2 = 0$.
- we are in the process of analyzing the results using the recent estimates of LCSR form factors with full correlations dictated by the symmetries at kinematic end points
- a similar analysis is being done for the high q^2 regime using Lattice form factors.
- we estimate the hadronic contribution from available data and have corresponding predictions for the angular observables
- the code we use to do the analysis is public (SusyFit pre-release)

For now, no anomaly can be claimed with any level of human confidence.

Look, if you had, one shot or one opportunity
To seize everything you ever wanted in one moment
Would you capture it, or just let it slip?

Eminem

Thank you…!!

To my Mother and Father, who showed me what I could do,

and to Ikaros, who showed me what I could not.

"To know what no one else does, what a pleasure it can be!"

– adopted from the words of

Eugene Wigner.