Delta Observables to establish New Physics, and MC simulations - Part II

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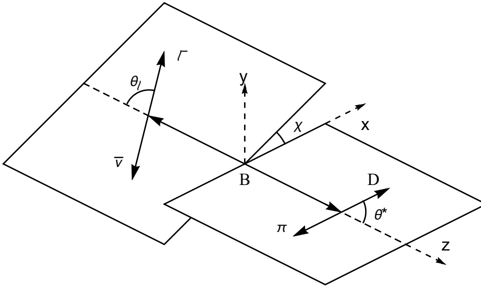
Talk Based on : 2203.07189 [hep-ph]

Snowmass 22, Cincinnati,
May 18, 2022

Flavour Changing Charged Current B-decay

1. Semileptonic decays are theoretically clean : Leptonic current is decoupled from the hadronic current.

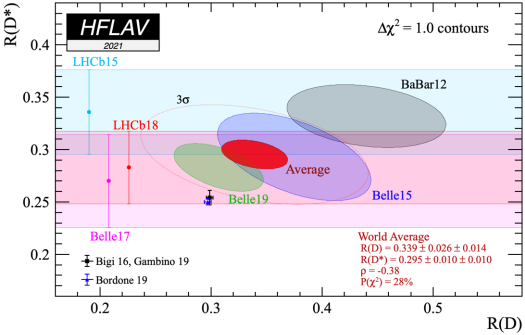
2. Here, we focus on $B \to D^* \ell \nu$ because :
   - Useful in the extraction of $|V_{cb}|$.
   - Testing CKM unitarity.
   - Sensitive probes of New Physics.
   - Unlike the $B \to K^* \ell\ell$ decay, this one does not suffer from pollution by charm resonances.
   - Test Lepton Flavour Universality of the SM.
   - Persistent hints of NP in τ modes and now in μ-modes.



Clean Observables

Lepton-flavour violating observables :

$$R_{D^{(*)}} = \frac{\mathcal{B}(\bar{B}\to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}\to D^{(*)}\ell\bar{\nu}_\ell)} \text{ (with } \ell = e \text{ or } \mu)$$

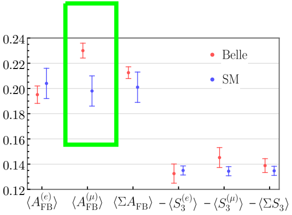


Obs	SM	WA
$R^{\tau/\ell}_{D^*}$	0.258 ± 0.005 *HFLAV 2019*	$0.295 \pm 0.011 \pm 0.008$ *HFLAV 2019*
$R^{\tau/\ell}_{D}$	0.299 ± 0.003 *HFLAV 2019*	$0.340 \pm 0.027 \pm 0.013$ *HFLAV 2019*
$R^{\tau/\mu}_{J/\psi}$	0.283 ± 0.048 *Watanabe 2017*	$0.71 \pm 0.17 \pm 0.18$ *LHCb 2017*
$R^{\mu/e}_{D^*}$	~ 1.0	$1.04 \pm 0.05 \pm 0.01$ *Belle 2017*

Possible new physics in tau!

Angular Observables

- The electron and muon data are in good agreement with SM!
- Hence, these modes were always used in the extraction of V_{cb}.



https://arxiv.org/abs/2104.02094

- Study of angular observables using the binned CP-averaged measurements of the four single-differential distributions provided by Belle done by Bobeth et. al *Phys. Rev. D 100 (2019), 052007* *https://arxiv.org/pdf/2104.02094.pdf*
- Observables integrated over the entire q^2 range.
- Reports a $> 2\sigma$ anomaly in A_{FB}^{μ}.

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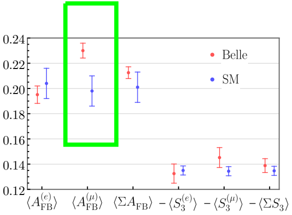

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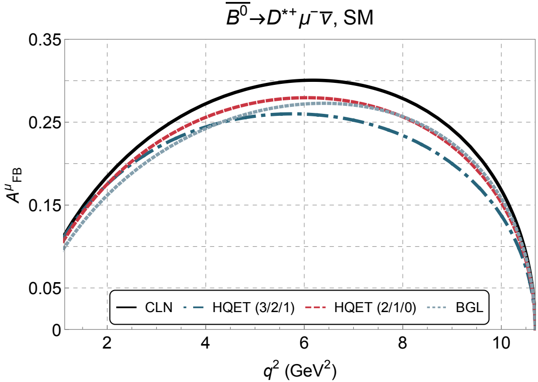
Is it possible to study the distribution of angular observables as function of q^2? - Future physics goals at Belle II/LHCb upgrade

An example : Forward-backward Asymmetry

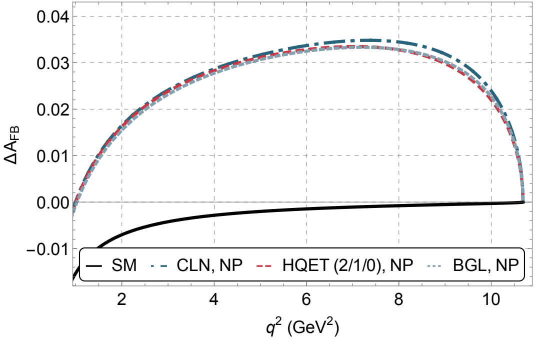
$$\frac{d^2\Gamma}{dq^2\, d\cos\theta_\ell} = \frac{d\Gamma}{dq^2}\left(\frac{1}{2} + A_{FB}\cos\theta_\ell + \frac{1-3\tilde{F}_L^\ell}{4}\,\frac{3\cos^2\theta_\ell - 1}{2}\right)$$



Preliminary plot, theory errors to be included soon.

- Difficult to disentangle NP from SM due to heavy dependence on form factors.
- Just like the $K^*\ell\ell$ case, we instead consider Δ-observables with potential sensitivity to NP.

Future of Measurements : $\Delta X = X^{\mu} - X^{e}$



- In case of SM, there is an almost exact cancellation of the hadronic uncertainties.
- $\Delta A_{FB}^{SM} \approx 0$
- Deviation from SM due to potential NP can be reliably extracted.

Δ Angular Observables

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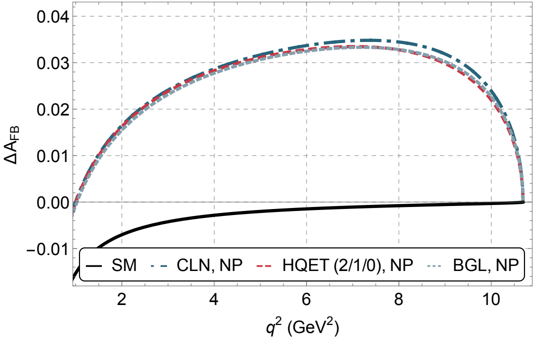

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What kinds of NP would provide potential signals in experiments?

MC for NP in $b \to c\ell\bar{\nu}$ decays

To answer this question we now have a new Monte-Carlo based on Evtgen:
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$$\mathcal{H}_{eff} = \frac{G_F V_{cb}}{\sqrt{2}} \Big\{ (1 + g_L) \left[\bar{c}\gamma_\mu(1-\gamma_5)b\right] \left[\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell\right]$$

$$+ g_R \left[\bar{c}\gamma_\mu(1+\gamma_5)b\right] \left[\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell\right]$$

$$+ g_S \left[\bar{c}b\right] \left[\bar{\ell}(1-\gamma_5)\nu_\ell\right]$$

$$+ g_P \left[\bar{c}\gamma_5 b\right] \left[\bar{\ell}(1-\gamma_5)\nu_\ell\right]$$

$$+ g_T \left[\bar{c}\sigma^{\mu\nu}(1-\gamma_5)b\right] \left[\bar{\ell}\sigma_{\mu\nu}(1-\gamma_5)\nu_\ell\right] \Big\} + h.c.$$

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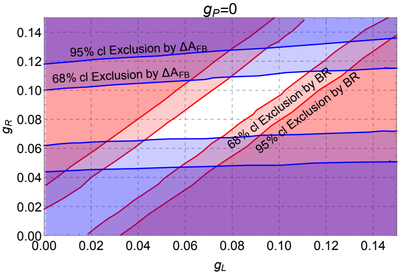
Caveats :

1. Neutrinos are always left-handed.
2. The scalar matrix element $\langle D^* | \bar{c}b | \bar{B} \rangle = 0$
3. SM case : $g_L = g_R = g_P = g_T = 0$
4. Hadronic matrix elements are expressed in terms of form factors which are non-perturbative objects (cannot be calculated form first principles of QCD).

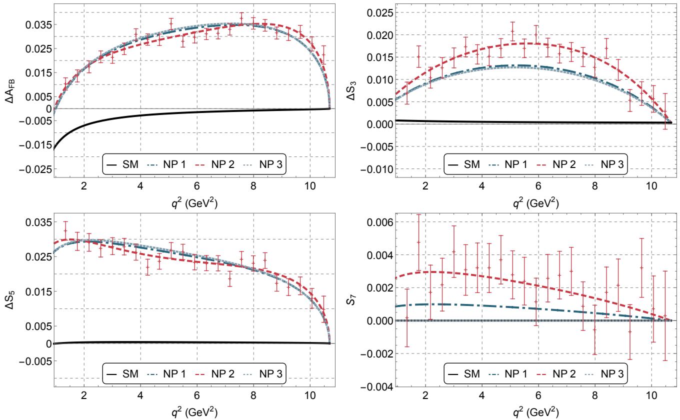
NP Analysis

- We pick out a few NP scenarios as listed below.
- The choice is motivated such that :
  - the ratio of semi-leptonic branching fractions is constrained to be within 3% of unity.
  - they are able to explain the"experimental" $\langle \Delta A_{FB} \rangle$: 0.0349 ± 0.0089.
  - they also satisfy constraints on other angular observables such as $\langle \Delta F_L \rangle^{exp} = -0.0065 \pm 0.0059$ and $\langle \Delta \tilde{F}_L \rangle^{exp} = -0.0107 \pm 0.0142$.

	g_L	g_R	g_P
Scenario 1:	0.06	0.075	0.2 i
Scenario 2:	0.08	0.090	0.6 i
Scenario 3:	0.07	0.075	0



Correlated Angular Asymmetries @ Belle II

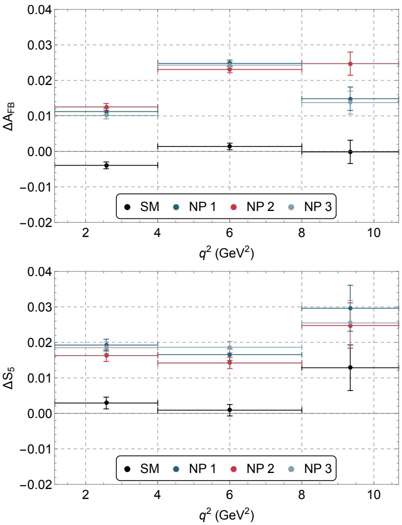


MC shown for 50 ab^{-1} data set in q^2 bins of 0.4 GeV^2

- If there is NP, then one will observe signals in other angular asymmetries, not just in ΔA_{FB} .
- True CP violating observable S_7 in presence of complex new physics.

Belle II Sensitivities

- Coarse binning could be done to begin with.
- Here we use Belle fiducial cuts :
  - $p_T^{\mu,e} > 0.8$ GeV
  - $p_T^{\pi} > 0.1$ GeV
  - Angular acceptance of all final state particles : $-0.866 < \cos\theta < 0.956$
- Note that we use the same p_T cut for electron and muon since we did not include detector efficiencies for the leptons separately.



Summary & Outlook

- Distributions of angular asymmetries in $B \to D^* \ell \nu$ are interesting and important for the future RPF.
- We expect angular asymmetries to provide tighter constraints on NP LFU couplings.
- We propose Δ-observables to be measured by Belle II which is ideally suited for such studies.
- We now have the MC generator for NP studies in such decays.
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THANK YOU!