An Event Generator For New Physics in $B \to D^* \ell \nu$ decay & Angular Asymmetries

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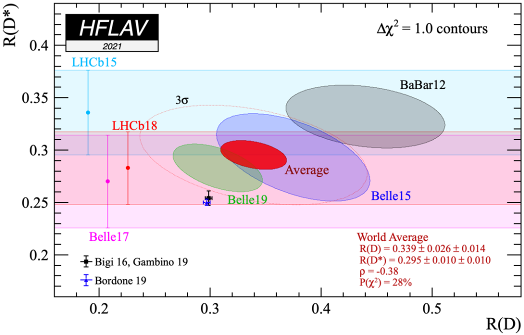
Talk Based on : ***2203.07189, 2206.11283 [hep-ph]***

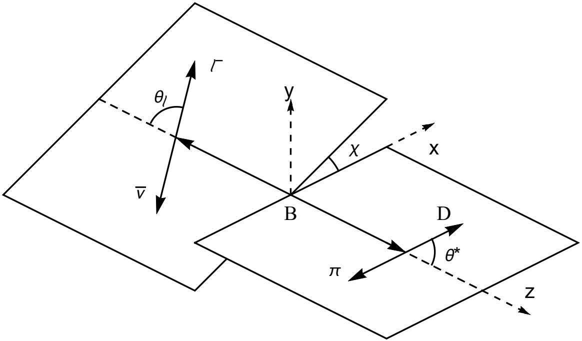
Flavour Changing Charged Current B-decay

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.
   - Test Lepton Flavour Universality of the SM.
   - Persistent hints of NP in τ modes and now in μ-modes.



See talk by Monika Blanke

Angular Distribution in $B \to D^* \ell \nu$

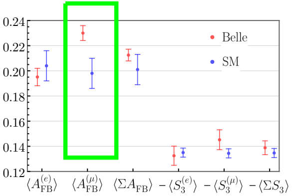


- Belle provided the first time lepton-flavour specific single-differential distribution data for each of the 4 kinematic variables

  Phys. Rev. D 100 (2019), 052007

- They used it to extract V_{cb} and test lepton universality ratio (μ/e).
- The electron and muon data are in good agreement with SM.

Angular Observables

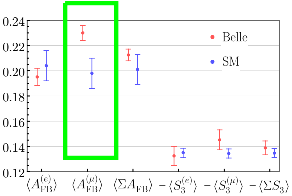


https://arxiv.org/abs/2104.02094

- 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} and $\sim 4\sigma$ anomaly in $\Delta A_{FB} = A_{FB}^{\mu} - A_{FB}^{e}$.

Are these angular observables really clean?

Angular Observables



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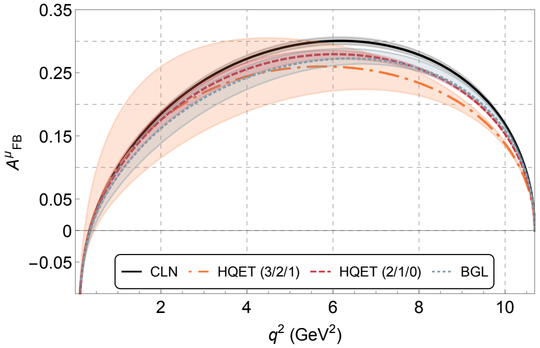
Is it possible to study the distribution of angular observables as function of q^2? - Future physics goals at Belle II/LHCb upgrade

Forward-backward Asymmetry

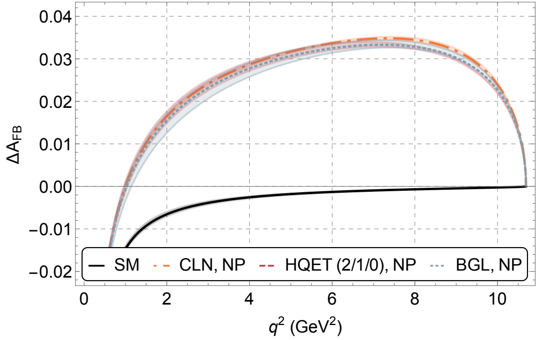
$$\frac{d^2\Gamma}{dq^2\, d\cos\theta_\ell} = \frac{d\Gamma}{dq^2}\left(\frac{1}{2} + A_{FB}\cos\theta_\ell + \frac{1-3\,\tilde{F}_L^\ell}{4}\,\frac{3\cos^2\theta_\ell - 1}{2}\right)$$



- Difficult to disentangle NP from SM due to heavy dependence on form factors.
- We instead consider Δ-observables with potential sensitivity to NP.

Δ Angular Observables

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



- In case of SM, there is an almost exact cancellation of the hadronic uncertainties.
- $\Delta A_{FB}^{SM} \approx 0$ except at threshold where $A_{FB}^{\ell} \to -1$.
- Deviation from SM due to potential NP can be reliably extracted.

Δ Angular Observables

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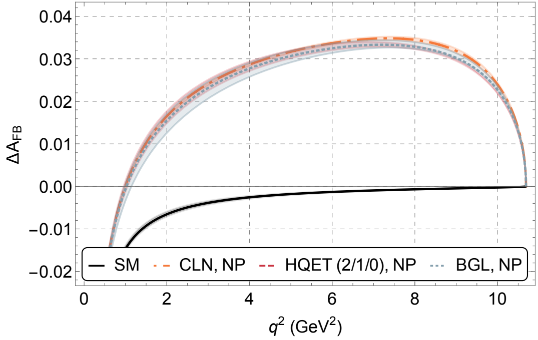

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What kinds of NP would provide potential signals in experiments?

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:
https://github.com/qdcampagna/BTODSTARLNUNP_EVTGEN_Model

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$$\mathcal{H}_{eff} = \frac{G_F V_{cb}}{\sqrt{2}} \Big\{ (1 + g_L) [\bar{c}\gamma_\mu(1-\gamma_5)b] [\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell] + g_R [\bar{c}\gamma_\mu(1+\gamma_5)b] [\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell] + g_S [\bar{c}b] [\bar{\ell}(1-\gamma_5)\nu_\ell] + g_P [\bar{c}\gamma_5 b] [\bar{\ell}(1-\gamma_5)\nu_\ell] + g_T [\bar{c}\sigma^{\mu\nu}(1-\gamma_5)b] [\bar{\ell}\sigma_{\mu\nu}(1-\gamma_5)\nu_\ell] \Big\} + h.c.$$

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

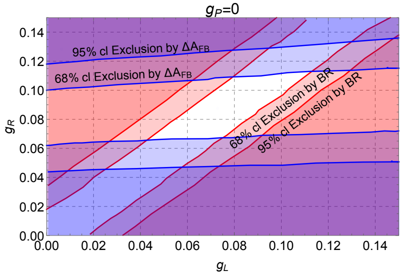
Caveats :

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).

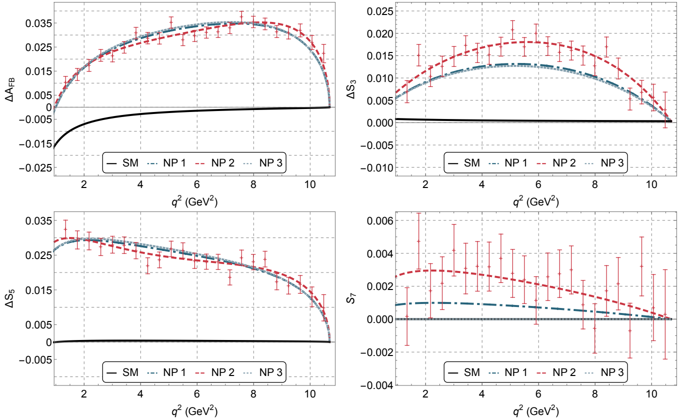
New Physics Analysis

- 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



Distributions of Angular Asymmetries



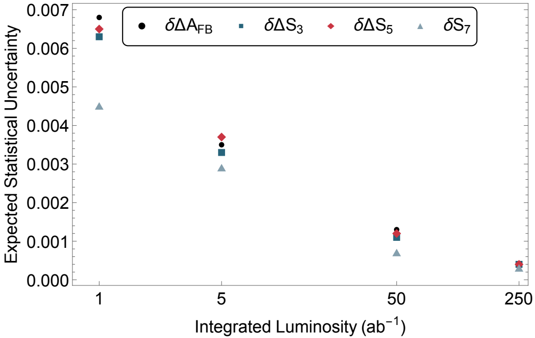
- True CP violating observable S_7 in presence of complex new physics.

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

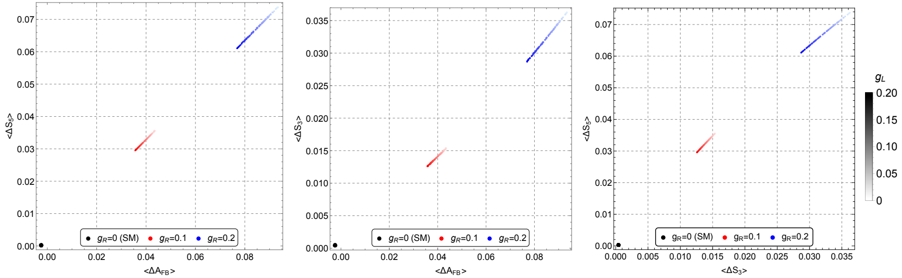
Theoretical Predictions & Belle II Sensitivities

	$\langle \Delta A_{FB} \rangle$ %	$\langle \Delta S_3 \rangle$ %	$\langle \Delta S_5 \rangle$ %	$\langle S_7 \rangle$ $\times 10^{-3}$
SM:	-0.252±0.004	0.0441±0.0007	0.0286±0.0013	0
NP 1:	2.89±0.05	1.08±0.04	$2.44^{+0.02}_{-0.03}$	0.7±0.01
NP 2:	$2.89^{+0.05}_{-0.06}$	$1.49^{+0.05}_{-0.04}$	$2.43^{+0.02}_{-0.03}$	2.0±0.1
NP 3:	$2.94^{+0.04}_{-0.05}$	1.04±0.04	$2.47^{+0.03}_{-0.02}$	0

- 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.



Correlated Angular Asymmetries



- If there is NP, then one will observe signals in other angular asymmetries, not just in ΔA_{FB}.
- If experiments measure ΔA_{FB} in future without observing a ΔS_5 (say), then the signature does not indicate new physics.
- The right-handed coupling mainly drives correlation in absence of tensor NP.

Summary & Outlook

- Distributions of angular asymmetries in $B \to D^* \ell \nu$ are interesting and important.
- We expect angular asymmetries to provide tighter constraints on NP LFU couplings.
- We propose Δ-observables to be the future of experimental measurements for this mode.
- We now have the MC generator for NP studies in such decays.
- We have pointed out possible NP scenarios that can generate $\Delta A_{FB} \sim 3\%$ and can be extracted by experiments.
- A lot can be achieved at and beyond the 50 ab^{-1} of Belle II.

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THANK YOU!