PROCEEDINGS OF SCIENCE

HAMMER: Reweighting tool for simulated data samples

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Modern flavour physics experiments, such as Belle II or LHCb, require large samples of generated Monte Carlo events. Monte Carlo events often are processed in a sophisticated chain that includes a simulation of the detector response. The generation and reconstruction of large samples is resource-intensive and in principle would need to be repeated if e.g. parameters responsible for the underlying models change due to new measurements or new insights. To avoid having to regenerate large samples, we work on a tool, The Helicity Amplitude Module for Matrix Element Reweighting (HAMMER), which allows one to easily reweight existing events in the context of semileptonic $b \to q\,\ell\,\bar{\nu}_\ell$ analyses to new model parameters or new physics scenarios.

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1. Introduction

Precision measurements in flavour physics require large data sets from modern flavour physics experiments like Belle II or LHCb and are often matched with Monte Carlo simulations which are several times the size of the measured dataset. The generation and reconstruction of these Monte Carlo simulations are very resource intensive, as they typically include a sophisticated detector simulation to make the simulated sample as comparable to the recorded data samples, as possible. A re-generation of these simulated samples would be required if e.g. parameters of the underlying models change due to new measurements or new insights. However, the process of updating samples generated with outdated model parameters can also be done by reweighting the existing events to new model parameters or even New Physics scenarios via the application of event weights. In the context of $b \to q\ell\bar{\nu}_\ell$ decays, the calculation of the weights for event by event reweighting can be handled in a common way for most decays and can thus be incorporated into a single tool, called the Helicity Amplitude Module for Matrix Element Reweighting (HAMMER). How this tool works will be described in the following.

2. Method

The sample reweighting is carried out event by event by calculating the analytical expressions of the corresponding decay rates using the full kinematic information of the $b \to q\,\ell\,\bar{\nu}_\ell$ decay. Written down the decay rate can be expressed as:

$$\frac{d\Gamma(B \to X\ell\nu_\ell)}{dq^2} = \frac{G_F^2}{(2\pi)^3}|V_{ij}|^2 \frac{(q^2-m_\ell^2)^2|p_X^*|}{12m_B^2 q^2}\left\{(H_+^2(q^2)+H_-^2(q^2)+H_0^2(q^2))\left(1+\frac{m_\ell^2}{2q^2}\right)+\frac{3}{2}\frac{m_\ell^2}{q^2}H_s^2(q^2)\right\} \tag{2.1}$$

The nonperturbative QCD effects described by the hadronic form factors are encoded in the Helicity Amplitudes $H_+^2(q^2), H_-^2(q^2), H_0^2(q^2)$ and $H_s^2(q^2)$. Using this formalism, a large range of models and decays can be implemented, among those for example $\bar{B} \to D^{(*)}\ell\bar{\nu}_\ell$ or $\bar{B} \to \pi\ell\bar{\nu}_\ell$. Furthermore the $\bar{B} \to D^{(*)}(\to D\pi)\,\tau(\to \ell\bar{\nu}_\ell\nu_\tau)\,\bar{\nu}_\tau$ decay as described in reference [1] can be implemented. Since the decay rates are calculated in terms of helicity angles at amplitude level, they are modular with respect to different τ and $D^{(*)}$ decay modes, meaning that it is easily extendable for the different final states. Furthermore reweighting to New Physics scenarios, e.g. by adding extra scalar, vector or tensor couplings can also be done using this tool. A vector with the weight w_i for each event i and the systematic uncertainties σ_i from the model is returned to the user. The weight is calculated in the following way:

$$w_i = \frac{\Gamma_{\text{old}}}{\Gamma_{\text{new}}}\frac{d^n\Gamma_{\text{new}}/d\mathbf{x}}{d^n\Gamma_{\text{old}}/d\mathbf{x}} \tag{2.2}$$

where Γ_{old} denotes the decay rate written down for the model implemented in the Monte Carlo, and Γ_{new} denotes the decay rate for updated model. This process of reweighting for $\mathbf{x} = q^2$ for $B \to D^*\ell\bar{\nu}_\ell$ is shown in Figure 1.

3. Examples

3.1 2HDM

One example for reweighting to a new physics scenario that can be easily implemented is a

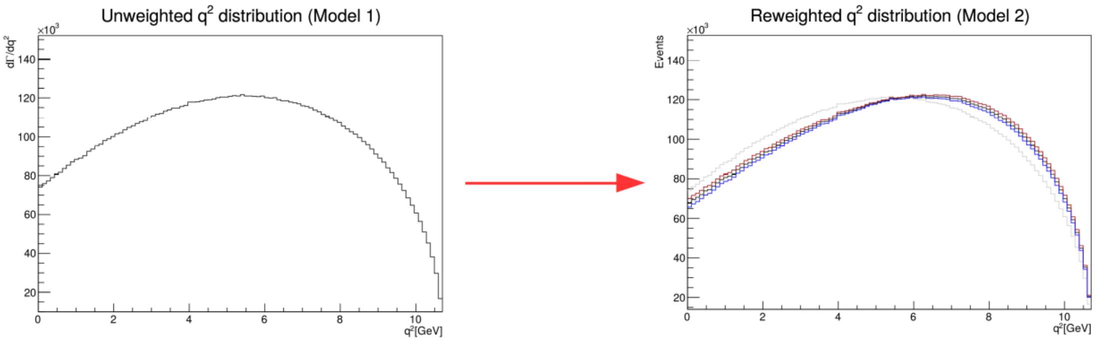

Figure 1: Plot showing the process of reweighting done with HAMMER. Shown in red and blue are the theoretical uncertainties of the new model in use [2] while the former model is shown in light grey [3].

2HDM Type-II scenario for $\bar{B} \to D^* \tau \bar{\nu}_\tau$ decays. In this model, charged Higgs bosons contribute to the mediation of the $b \to c$ transition in addition to the $W^\pm$ bosons, thus modyfiing the decay rate of these processes. The coupling strength of the charged Higgs boson depends on the ratio of the vacuum expectation values of the Higgs doublets, $\tan\beta$, and the charged Higgs mass $m_{H^\pm}$. The change of the differential decay rate $\frac{d\Gamma}{dq^2}$ changes in dependence of the ratio $\frac{\tan\beta}{m_{H^\pm}}$, which can be seen in Figure 2.

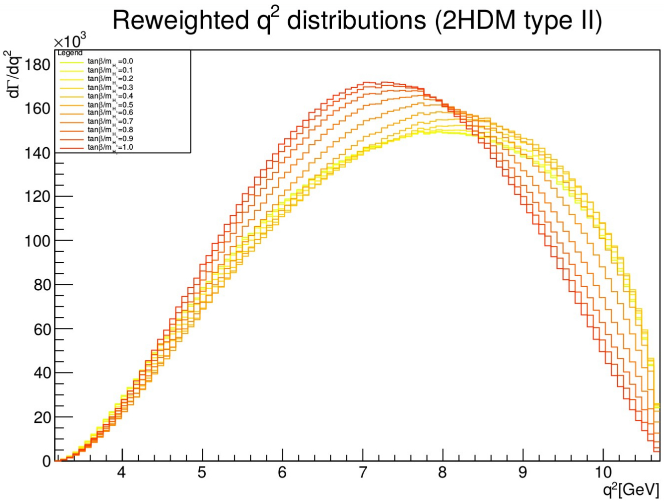

Figure 2: Reweighting of $\bar{B} \to D^* \tau \bar{\nu}_\tau$ for ten different configurations of $\frac{\tan\beta}{m_{H^\pm}}$, ranging from 0 (SM in green) to 1 (full 2HDM type II in red) done with HAMMER

3.2 New generic operators in $\bar{B} \to D^{(*)} \tau (\to \ell \bar{\nu}_\ell \nu_\tau) \bar{\nu}_\tau$ decays

HAMMER plans to include a range of generic new operators for $\bar{B} \to D^{(*)} \tau \bar{\nu}_\tau$ decays taken from [1]. Analyses of $\bar{B} \to D^{(*)} \tau \bar{\nu}_\tau$ decays have typically performed a one dimensional scan in $q^2 = (p_B - p_{D^{(*)}})^2$. With the result from [1] it is possible to do a full 10 dimensional analysis in q^2 and the decay angles and kinematics of $\bar{B} \to D^{(*)} \tau (\to \ell \bar{\nu}_\ell \nu_\tau) \bar{\nu}_\tau$, resulting in better sensitivity to effects e.g. from New Physics. As a means to demonstate the additional sensitivity to generic new operators using the full 10-dimensional information as compared to using the q^2 information only, multivariate analysis techniques are employed. To quantify the difference in separation power between the Standard Model scenario and a scenario including a generic new operator with a certain coupling strength by using the full kinematic information as compared to only q^2, we compute CL_s defined as:

$$CL_s = 1 - \frac{\int_{-\infty}^{\mu} \mathscr{O}_{NP}(x)dx}{1 - \int_{\mu}^{\infty} \mathscr{O}_{SM}(x)dx} \tag{3.1}$$

where $\mathscr{O}$ is the output distribution of a multivariate analysis (MVA) approach that has been trained to distinguish between a scenario including a generic new operator ($\mathscr{O}_{NP}$) and the Standard Model scenario ($\mathscr{O}_{SM}$) with μ being the median of $\mathscr{O}_{NP}$. The result is shown in Figure 3.

The following results for CL_s are obtained:

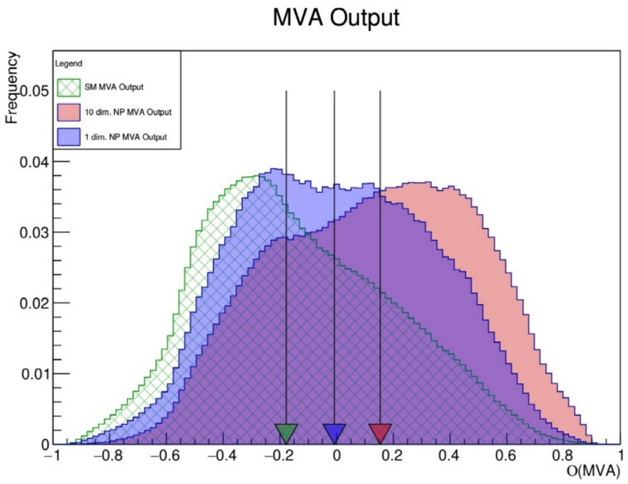

Figure 3: MVA response for training the SM scenario vs. a NP scenario with a generic new operator once with only q^2 and once with the full kinematic information. The arrows show the median of the corresponding distribution.

- $CL_s(q^2) = 0.3319$
- $CL_s(10D) = 0.5619$

This shows that using the full kinematic information results in a separation power almost twice as large for distinguishing between the Standard Model scenario and a scenario involving a generic new operator, making the use of the full kinematic information much more favorable as compared to only using q^2

References

[1] Z. Ligeti, M. Papucci and D. J. Robinson, arXiv:1610.02045 [hep-ph]

[2] I. Caprini, L. Lellouch and M. Neubert, Nucl. Phys. B **530** (1998) 153 doi:10.1016/S0550-3213(98)00350-2 [hep-ph/9712417]

[3] D. Scora and N. Isgur, Phys. Rev. D **52** (1995) 2783 doi:10.1103/PhysRevD.52.2783 [hep-ph/9503486]