Executive Summary of the MITP Topical Workshop

“LHCb and Belle II Opportunities for Model Builders”

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28 January - 1 February 2019

Goals of the Workshop

Flavor physics provides a superb tool for probing physics beyond the Standard Model (SM). The intriguing anomalies reported by LHCb and other experiments in the semileptonic decays of B-mesons have drawn a lot of attention to the field since, if confirmed, they would represent the first pieces of evidence of new phenomena at the TeV scale. This has triggered a tremendous activity in the model building arena, helping the community to get a clear picture of the different frameworks available to accommodate the data.
While waiting for more data to be collected and analysed by both LHCb and Belle-II experiments, on the theory side it is crucial to study in detail possible predictions of the various New Physics (NP) scenario, that can be tested by these experiments. In order for this program to be successful it is important for theorists and experimentalists to come together. This is precisely the goal of this workshop, to bring together Belle II and LHCb experimentalists and model builders to discuss the opportunities and new schemes for future measurements, in view of the present results.

Structure of the Workshop

The structure of the workshop consisted of approximately three talks per day. As far as possible, we tried to give priority to young scientists and in particular to those without permanent jobs. The time allocated for each talk was about one hour; indicatively split in a 40' presentation and a 20' discussion. The time slots were quite flexible, allowing for extended discussions for most of the talks, often going beyond the 1h limit. A significant amount of discussion was also stimulated by the informal atmosphere during the whole workshop. This allowed the participants to engage more and profit from the event. The workshop was a very formative experience for a non-negligible number of PhD students and one MSc student.

Scientific Highlights

Experiments

The LHCb experiment has been at the center of B-physics for the past several years, thanks to its ability to produce very large number of B mesons and to analyse their decay products in great detail. This has enabled very precise Lepton Flavor Universality (LFU) tests in rare semileptonic B-decays, which revealed striking deviations from the SM prediction. The deviations observed in these observables turned out to be compatible, from the NP point of view, with a deviation from SM predictions in some specific angular distribution of rare $B \to K^*\mu\mu$ decay. Another crucial set of measurements are further LFU tests, but in the very frequent charged-current semileptonic decays $B \to D(^*)\ell\nu$. The ratios of these branching ratios into taus vs. muons is called $R(D(^*))$. LHCb was able to confirm deviations from the SM previously observed by the Babar and Belle experiments, bringing the significance of the deviations to the 4σ level.

In order to be able to confirm without possible doubts those deviations it is necessary for another independent experiment to perform the same measurements. Belle-II, a B-factory which just started taking data, will be able to do just that. In particular, thanks to the much cleaner environment than LHCb, it will be able to improve drastically the precision in all decays involving missing energy, such as those in $R(D(^*))$, allowing also to perform precise studies of differential distributions. Belle-II will also be able to perform independent measurements on the neutral-current LFU ratios $R(K)$ and $R(K^*)$.

The vast majority of NP models addressing the B-meson anomalies, however, also predict correlated effects in other observables. For example, large effects in $B \to K^*\nu\nu$, $B \to K^*\tau\tau$, $\tau \to \mu\gamma$ are that often predicted will be tested by Belle-II as well.

Theory

A well defined line of action to verify the presence of new physics in flavor data is to define new observables, accompanying those already showing hints of new phenomena. In particular, there is room to define new angular observables in

B→D(*)ℓv decays, complementary to R(D) and R(D*), which could show hints of new physics even if the anomaly in those branching ratios would disappear in the future. One can also derive an approximate sum rule for R(Λc)/R(Λc)_SM, which will become an experimental cross-check of R(D^(*)) anomaly, once data on R(Λc) is released. Moreover, polarization observables are well suited to distinguish among different new physics scenarios. On the other hand, it is also possible to verify the presence of physics beyond the SM by increasing the accuracy of the SM prediction in those observables already featuring some discrepancy with the SM. This can be achieved in particular by a more precise parametrization of hadronic matrix elements, including higher orders in the velocities or a systematic parametrization of 1/mc^2 corrections.

Another task one should encompass in the quest for new physics is to be as exhaustive as possible in studying possible explanations of the flavor anomalies. One should consider in particular going beyond some simplifying assumptions when they change the phenomenology in a significant way. The presence of right-handed couplings to quarks in the case of vector leptoquarks, or loop induced explanations to R(K(*)), or considering right-handed neutrinos as explanation of R(D(*)) constitute particular examples of this. Among the different models trying to explain simultaneously the anomalies appearing in charged currents and neutral currents, the case of a vector leptoquark, singlet under SU(2)_L, stands out because of its minimal matter content. However, not so much attention has been paid to the case where right-handed couplings to quarks are also present, which has different and testable phenomenological signatures. Another interesting class of models correspond to those where the anomalies appearing in neutral currents, R(K) and R(K*), are explained with loop induced new physics. If one wants to address in addition (g-2)_μ, while being in agreement with Bs-Bs mixing data, it is essential to turn on RH couplings to quarks. Finally, simplified models should be complemented with UV complete scenarios, which allow e.g. to study in detail the impact of radiative effects and connect different experimental searches. This also shows the importance of present experimental constraints on flavor-violation, in particular on meson-antimeson mixing. These observables can receive contributions not only directly from operators generated in the ultraviolet, but also indirectly via renormalisation-group evolution. Given the strong sensitivity to NP of these observables it is thus important to calculate and to take these effects into account.

One should also try to connect flavor anomalies with the question of naturalness, which has been always so fruitful in producing interesting ideas. In this sense, the concept of partial compositeness offers a beautiful bridge between both fields, for it complements nicely the strongly coupled solution to the hierarchy problem and also offers a well motivated framework to understand flavor at the TeV scale. Such paradigm can also explain neutrino masses, which leads to interesting predictions for neutrino textures. The hierarchy problem also motivates the appearance of light axion like particles, which can then be looked for in flavor experiments. Changes in basic cuts like Delta R or pT_{min} can have a big impact on current searches and are a first step in this direction.

Exotics

Going beyond flavor physics, we also discussed how Belle-II will be sensitive to very light New Physics, possibly involved in a dark sector which could address the Dark Matter problem. For example, Belle-II will be able to put important constraints on the dark photon parameter space, as well as testing specific regions in axion-like models.

Conclusions

The MITP topical workshop "LHCb and Belle II Opportunities for Model Builders" brought together experts in the field of flavor physics, both experimentalists and theoreticians. The main topics of discussion were the future prospects for precision flavour measurements at LHCb and Belle II experiments, with a focus on rare and semileptonic B-meson decays and related transitions. The workshop also covered recent developments in the related Standard Model calculations and novel ideas for new physics interpretations of the ongoing B-anomalies.

This workshop helped clarify the opportunities in the upcoming flavour physics data and provided useful guidelines for the experimentalists. At the same time, it also helped model builders to understand the scope of the exciting experimental endeavour ahead.

We are grateful to all the participants who brought many interesting topics for discussion and to the MITP secretaries, who made the organisation of the workshop a pleasure.