Executive Summary of the mitp topical Workshop

Challenges in Semileptonic B decays

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Organized by

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The Scientific Case of the Workshop

The CKM matrix elements $|V_{ub}|$ and $|V_{cb}|$ are important ingredients in the determination of the unitarity triangle of the CKM matrix. They also serve as input quantities in FCNC processes relevant for searches of physics beyond the Standard Model. For both parameters the exclusive determination is about 3σ below the inclusive one. This discrepancy has survived several independent checks and could be an indication of new physics.

Thirty-three participants met in Mainz to develop a medium-term strategy of analyses and calculations aimed at the resolution of the puzzle. Lattice and continuum theorists discussed with experimentalists how to reshape the semileptonic analyses in view of the much larger luminosity expected at Belle-II and how to best exploit the new possibilities at LHCb, searching for ways to systematically validate the theoretical predictions in both exclusive and inclusive B decays.

The format of the Workshop

The program took place during a period of five days, allowing for ample discussion time among the participants. Each of the five workshop days has been devoted to a specific topic: the inclusive and exclusive determinations of $|V_{cb}|$ and $|V_{ub}|$, and on the last day the semileptonic B decays with heavy leptons in the final state. In the mornings we had overview talks from the experimental and theoretical sides, reviewing the main aspects and summarizing the state of the art. In the late afternoon we organized discussion sessions led by experts of the various topics, addressing questions that have been brought up before or during the morning talks.

Inclusive determination of $|V_{cb}|$

The theoretical predictions in this case are based on an operator product expansion, and better control on all higher order corrections is needed to reduce theoretical uncertainties, which are already dominant. In this respect, it would be important to have the QCD perturbative corrections to the coefficient of the Darwin operator and to check the treatment of QED radiation in the experimental analyses. A full $O(\alpha_s^3)$ calculation of the total width may be within reach with recently developed techniques. From the

experimental point of view, new and accurate measurements of the third hadronic moment would have an impact on the fit, which may also benefit from the measurement of the forward-backward asymmetry as proposed by Turzcyk. The importance of having global fits to the moments in different schemes and by different groups has also been stressed. This calls for an update of the 1S scheme fit and could lead to a cross-check of the present theoretical uncertainties. Lattice QCD already provides inputs to the fit with the calculation of the c-quark mass. Further progress on the b quark mass and the ratio m_c/m_b is expected, and it might also be possible to calculate the leading order heavy-quark parameters μ_π^2 and μ_G^2, or at least provide additional information that can be fed into the fits. LHCb can in principle provide additional measurements with vanishing cut on the charged lepton energy.

Exclusive determination of $|V_{cb}|$

We discussed several incremental and qualitative improvements in lattice QCD. Of the latter, the most notable is to carry out a combined fit of the recoil dependence calculated in lattice QCD together with the measurements. This approach sidesteps an extrapolation of the experimental data to zero recoil, using a parametrization that may have outlived its utility. Two results for $B \to Dl\nu$, from the the Fermilab Lattice and MILC collaborations just before our workshop, and from the HPQCD collaboration since, show less tension with inclusive $|V_{cb}|$. A tantalizing pre-preliminary analysis of unblessed Belle data suggests even less tension. This approach is also possible with $B \to D^* l\nu$, and the discussions in Mainz emphasized the urgency to perform this analysis. The discussions addressed the fact that the QCD errors are now almost as small as effects from QED. Thus, further improvement must be theoretically made by properly studying the effect of QED radiation, especially the treatment of soft photons and photons that are neither soft nor hard and their sensitivity to the meson wave functions.

Inclusive determination of $|V_{ub}|$

This determination is based on various well-founded theoretical methods which agree nicely. Still, the NNLO corrections in the full phase space should be implemented and the various methods should be upgraded in order to make the best use of the Belle-II differential data based on much higher statistics. These data will make it possible to test the various methods and to calibrate them, as they will contain information on the shape functions. The SIMBA and NNVub methods seem to have the potential to fully exploit the $B \to X_u l\nu$ (and possibly radiative) measurements through combined fits to the shape function(s) and $|V_{ub}|$. The separation of $B^\pm$ and B^0 in the experimental analyses will certainly help constraining weak annihilation, but the real added value of Belle-II could be the ability to accurately measure spectra (M_X, q^2, E_l,...). A detailed measurement of the high q^2 tail might be very useful, also in view of attempts to check quark-hadron duality. Experimentally, better hybrid (inclusive+exclusive) Monte Carlos are badly needed; s-$\bar{s}$ popping should be investigated (how can K-veto be lifted?) The $b \to c$ background will be measured better, which will benefit these analyses.

Exclusive determination of $|V_{ub}|$

This determination relies on nonperturbative calculations of the form factor of $B \to \pi\ell\nu$ which, up to now, is the most precise channel. We discussed the status of the

LCSR calculations and several recent improvements in lattice QCD. In particular two recent lattice calculations by the Fermilab/MILC and the RBC/UKQCD collaborations, released just before the workshop, increase the central value by more than 1σ, when they are combined with the existing measurements of the $B \to \pi\ell\nu$ differential rate as a function of q^2. The Fermilab/MILC calculation alone leads to a remarkably small total error on $|V_{ub}|$, of about 4%. While at present the most precise extraction of $|V_{ub}|$ comes from $B \to \pi\ell\nu_\ell$, it has been clearly stated that in the future the golden channel will be $B_s \to K\ell\nu$ because here the lattice calculations are affected by smaller uncertainties. $B_s \to K\ell\nu$ will be accessibile at Belle-II in the run at the $\Upsilon(5S)$ and at the LHCb exploiting the huge amount of B_s already collected in the Run1. The great potential of LHCb has been demonstrated by the unexpected measurement of the partial rate $B(\Lambda_b \to p\mu\nu)/(\Lambda_b \to \Lambda_c\mu\nu)$ in the high q^2 region. This measurement, combined with a recent lattice determination of the relative form factors, has led to the first measurement of $|V_{ub}/V_{cb}|$ from baryonic b-decays with a relative uncertainty of only 7%. The result is compatible with the exclusive determination and only marginally compatible with the inclusive one. The baryonic charmless decay is also very interesting because the decay rate is also sensitive to possibile right-handed currents in the $b \to u$ transition. The LHCb result, combined with the constraints from $B \to \pi\ell\nu$ and the inclusive $B \to X_u\ell\nu$, does not favor contributions from RH currents. We discussed also other channels sensitive to right-handed currents, in particular $B \to \rho\ell\nu$ and the analogous B_s decay, $B_s \to K^*\ell\nu$.

Decays to tauonic final states

Tension with the Standard Model remains in semitauonic decays. BaBar's measurements of the branching ratios for $B \to Dl\nu$ and $B \to D^*l\nu$ exceed the SM prediction by 2.0σ and 2.7σ, respectively, or 3.4σ combined. Belle and LHCb analyses are underway and eagerly awaited. The nonzero-recoil form factors from lattice QCD, mentioned above, are useful here too.

The measurement of $B \to \tau\nu$ is not yet competitive with semileptonic decays for measuring $|V_{ub}|$, because of a 20% error. Belle-II will improve this. The corresponding lattice-QCD calculation is more precise, with an error of only 5%. That said, the mode is useful today to model builders trying to understand new physics explanations of the tension between inclusive and exclusive determinations of $|V_{ub}|$ (e.g., the right-handed currents mentioned above).

Conclusion

The workshop has been very successful and was appreciated by all participants. It brought together scientists from different disciplines working on the same subject. Various new ideas have been put forward in order to scrutinize our current understanding and eventually to resolve or confirm the current discrepancies. New calculations are still necessary and new analyses will be possible at Belle-II and LHCb. The discussion sessions have proven to be very useful to develop these ideas. The results of the workshop will be summarized in a short report to be posted on `arXiv.org`.