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Evaluation of Doctoral Thesis of Tadeas Bilka

The doctoral thesis of Tadeas Bilka consists of two main distinct parts: a measurement of the CP-violation in the $B^0 \to \eta_C K_S$ decays using Belle data and the alignment of the Belle II detector. Both parts are of high scientific value and are described by Tadeas Bilka in great detail. As such, the thesis represents an important steps in our understanding of the high energy physics and experimental methods thereby meeting the requirements for a doctoral degree.

Given an unusual combination of the physics analysis and description of the technical task, the thesis has an unusual composition. It starts with the description of the accelerator complex, KEKB, and SuperKEKB, for Belle, and Belle II measurements, respectively. The detectors themselves are described next. This composition provides Tadeas Bilka with an opportunity to perform a useful comparison between the two experimental setups with an emphasis on the challenges and improvements of Belle II.

Part II of the thesis is devoted to the measurement of time-dependent CP violation in the $B^0 \to \eta_C K_S$ decays. Tadeas Bilka starts with a brief theoretical introduction that discusses discrete symmetries of nature and the first experimental observation of the CP violation in the neutral kaon system. Tadeas Bilka continues with the discussion of the CP violation in the Standard Model, which is driven by the complex phase in the CKM quark-mixing matrix. The next sections describe the time-dependent CP violation measurements in the B-meson system and they contain many more details. The introduction ends with the motivation why it is important to compare the level of CP violation in different decay channels of B mesons, including pseudo-scalar η_C, and the current experimental status. Compared to the "golden" channel to measure CP violation, $B_0 \to J/\psi K_S$, the $B^0 \to \eta_C K_S$ channel is far less accurately known. The previous analysis at Belle used a clean $\eta_C \to p\bar{p}$ decay that however has a low branching fraction leading to large statistical uncertainty. This analysis was performed by Dr. Z. Dràsal as a doctoral thesis at Prague Charles University.

Tadeas Bilka continues the thesis with a description of the methodology to include more copious $\eta_C \to K^0_S K^+ \pi^-$ channel in the analysis. Tadeas Bilka clearly states that a significant part of the analysis was already performed by Dr. Z. Dràsal: technical developments such as the analysis framework and conveniently processed Belle data samples. The main contributions from Tadeas Bilka are in the optimization of the selection and background suppression, which is essential for this more challenging decay mode. It should be also noted that finalizing the analysis involving complex multi-dimensional fit is far from a trivial task too.

In chapters 5 to 8, Tadeas Bilka details the analysis steps such as event reconstruction, background suppression, determination of the peaking background contribution, fit model validation, time-dependent measurement, and various consistency checks. A particular emphasis is given to the treatment of the signal and background interference, which is an important source of systematic uncertainty due to the physics modeling. In the end, all tests yield good results and the systematic uncertainties are demonstrated to be under control. Tadeas Bilka reports the measurement of the CP violating parameters S_{CP} and A_{CP} in chapter 8. The results are consistent with the SM: S_{CP} is measured to be non-zero at the 3.4σ level while A_{CP} is consistent with zero. In the concluding chapter, Tadeas Bilka combines his results with the previous measurement from the BaBar collaboration that establishes CP violation parameter S_{CP} at more than a 5σ level. These results provide valuable information for the CP violation in the Standard Model, showing consistency between vector- and pseudo-scalar decay modes and thereby setting limits on new physics contributions.

The second part of the doctoral thesis is devoted to the Belle II tracker alignment. For these studies, Tadeas Bilka played the leading role at all stages, from the first implementation of the alignment code to the Belle II software to the validation of the alignment results. The role of Tadeas Bilka is hard to underestimate: the tracker alignment is essential for the physics performance of the Belle II detector, for time-dependent CP violation measurements in particular. The task involves determination of about 60000 parameters which may vary in time. The alignment work was performed by two students from Prague, Tadeas Bilka together with Jakub Kandra. Out of the two, Tadeas Bilka performed most of the tasks while Jakub Kandra implemented the sensor surface deformation parameters for the silicon tracker modules.

The description of the alignment procedure starts with methods for track fitting and alignment software. Tadeas Bilka is one of the developers of the GENFIT2 software used for track reconstruction. He also is the main developer to interface the alignment package Millepede II to the Belle II analysis software. Tadeas Bilka developed parameterisation of mis-alignment parameters for various subdetectors. An important novel development is an introduction of hierarchical alignment in which individual sensors can be grouped together to simplify parameterisation of coherent movements.

One of the alignment challenges is the presence of so called weak modes – transformations which are only weakly constrained by the procedure. Some of these modes can be controlled by introducing divers data samples, such as cosmic muon tracks and $e^+e^- \to \mu^+\mu^-$ events. Tadeas Bilka documents studies on alignment performance depending on relative representation of different samples and performes its optimization. Some of the transformation can not be determined and require external constraints. Tadeas Bilka discusses impact of these constraints, which play in particularly important role for the alignment of the Belle II drift chamber.

Tadeas Bilka implemented the alignment in the Belle II calibration framework. The automatation of the alignment procedure is essential given that the Belle II data taking is expected to span over decade. One of the surprising observations that the algmnent parameters undergo strong variation as a function of time. Tadeas Bilka reports detailed studies of the effect and ways to mitigate it.

An important development is the alignment which includes positions of drift chamber wires as free parameters. This required introduction of about 60000 parameters in the minimization. Studies of Tadeas Bilka triggered developments of the Millepede II code to include highly optimized linear algebra libraries. This reduced the time required for a complete alignment from days to below one hour, enabling much more detailed systematic checks.

In the end, the alignment performed on the data sample taken by the Belle II collaboration met the specification that residual mis-alignments have negligible impact on physics compared to the detector resolution. This was demonstrated in the recently published by the Belle II collaboration measurements of the D^0 and D^+ mesons lifetimes. While this analysis is not described in the doctoral thesis, Tadeas Bilka took an active part in this measurement as one of the analyzers.

To summarise, the doctoral thesis of Tadeas Bilka represents an important milestone for the understanding of CP violation in the Standard Model. It also servers as important step in development of tools to enable precision measurements at Belle II. The amount of work and excellent results achieved by Tadeas Bilka are very impressive and thus I believe he should be granted the PhD degree.

Sincerely Yours

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