Karlsruhe Institute of Technology

Department of Physics
Institute of Experimental Particle Physics
Institute for Astroparticle Physics
Prof. Dr. Torben Ferber (ETP)
Prof. Dr. Kathrin Valerius (IAP)
Prof. Dr. Markus Klute (ETP)
Dr. Nils Faltermann (ETP)

Exercises for Modern Experimental Physics III (Experimental Particle and Astroparticle Physics)

Summer term 2024

Exercise sheet Nr. 3 To be worked on until 06.06.2024

Semileptonic decays of B-mesons into charmed final states play an important role in the measurement of the CKM-matrix element V_{cb}, but also in the search for new physics beyond the Standard Model. In the Standard Model, the decays occur at tree level via the emission of a virtual W boson that changes the bottom quark into a charm quark. Figure 1 shows the Feynman diagram of a $\overline{\mathrm{B}} \to \mathrm{D}^* \ell \overline{\nu}_\ell$ decay, with ℓ denoting either an electron or a muon.

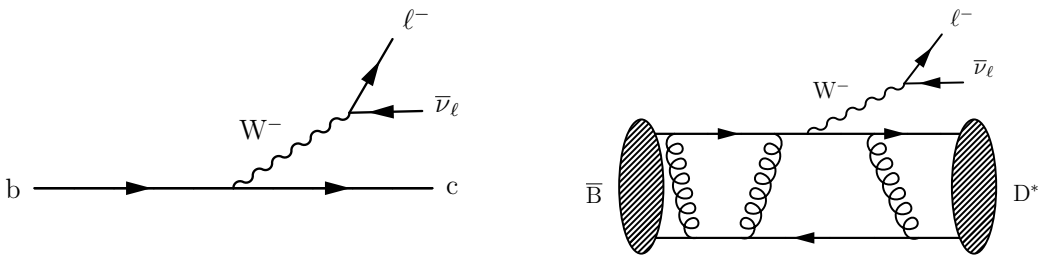

Figure 1: The semileptonic $\overline{\mathrm{B}} \to \mathrm{D}^* \ell \overline{\nu}_\ell$ decay at quark level (left) and in terms of mesons (right). The strong interaction influences the B-meson decay via the constant emission and absorption of, for instance, soft gluons. These non-perturbative effects depend on the four-momentum transfer from the $\overline{\mathrm{B}}$-meson system to the D*-meson system, denoted as $q^2 = (p_{\mathrm{B}} - p_{\mathrm{D}^*})^2$.

The $\overline{\mathrm{B}} \to \mathrm{D}^* \ell \overline{\nu}_\ell$ decay is very abundant: more than 10 % of all B-meson decays occur in this channel. Therefore, they are an ideal probe to search for new physics: for instance, the coupling of first- and second-generation leptons in the decay can be probed against the coupling of the third-generation τ lepton, or the decay topology can be used to search for massive neutrinos.

This exercise is inspired by two analyses made by the Belle Collaboration:

- Measurement of the decay $\mathrm{B} \to \mathrm{D}\,\ell\,\nu_\ell$ in fully reconstructed events and determination of the Cabibbo-Kobayashi-Maskawa matrix element $|V_{\mathrm{cb}}|$ [1].
- Search for the $\mathrm{B}^+ \to \mu^+\,\nu_\mu$ and $\mathrm{B}^+ \to \mu^+\,\mathrm{N}$ with inclusive tagging [2].

Please feel free to have a closer look at these publications, if you are interested in the topics touched in this exercise.

You can find the corresponding Jupyter Notebook in the `https://gitlab.etp.kit.edu/Lehre/modexph3_forstudents` repository. For this exercise it is sufficient to use the standard `Datenanalyse` container on the jupytermachine.

Exercise 1: Kinematic properties of B-meson decays (6 points)

Exercise 2: Boost into the signal B-meson rest frame (3 points)

Exercise 3: Reconstruction of the D^0 and D^* mesons (4 points)

Exercise 4: Particle identification (4 points)

Exercise 5: The D^* mass (3 points)

References

[1] Belle Collaboration, "Measurement of the decay $B \to D\ell\nu_\ell$ in fully reconstructed events and determination of the Cabibbo-Kobayashi-Maskawa matrix element $|V_{cb}|$", *Phys. Rev. D* **93** (Feb, 2016) 032006. doi:10.1103/PhysRevD.93.032006.

[2] Belle Collaboration, "Search for $B^+ \to \mu^+\nu_\mu$ and $B^+ \to \mu^+ N$ with inclusive tagging", *Phys. Rev. D* **101** (Feb, 2020) 032007. doi:10.1103/PhysRevD.101.032007.