# Inclusive Semileptonic B Meson Decays and the Determination of $|V_{cb}|$

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The Belle II experiment at the SuperKEKB is an asymmetric-energy $e^+e^-$ collider at KEK, Japan. Electrons and positrons are accelerated with beam energies of 7 GeV and 4 GeV, respectively, producing collisions slightly above the center-of-mass energy of approximately 10.58 GeV, corresponding to the $\Upsilon(4S)$ resonance, which predominantly decays into pairs of $B$ mesons. Belle II is a general-purpose detector consisting of several sub-detector systems arranged around the interaction point. Charged-particle vertexing and tracking are provided by the pixel detector (PXD), silicon vertex detector (SVD), and central drift chamber (CDC), while particle identification is performed using the Time-Of-Propagation (TOP) counter and aerogel ring-imaging Cherenkov detector (A-RICH). The electromagnetic calorimeter (ECL) measures the energy of electrons and photons, and the outer $K_L^0$ and muon detector (KLM) provides identification of muons and long-lived neutral kaons. A superconducting solenoid supplies a 1.5 T magnetic field for charged-particle momentum measurements. These detector systems provide the particle reconstruction and identification capabilities required for the inclusive $B \to X_c \ell \nu$ measurement.

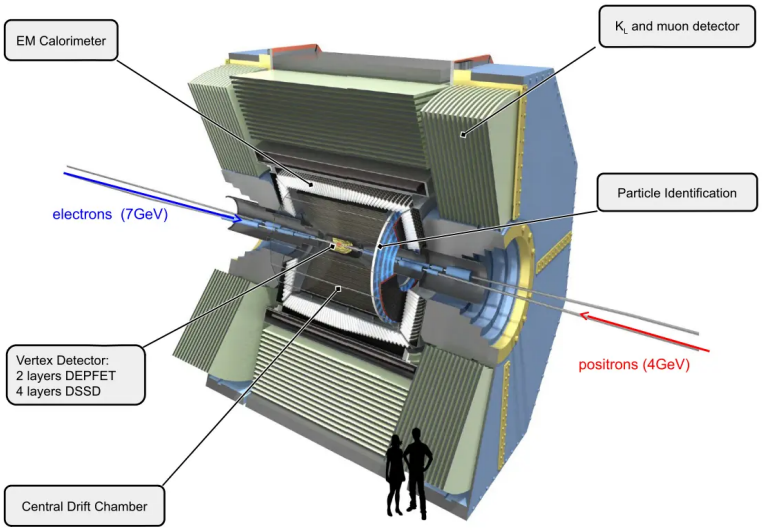


Abbildung 1: Overview of the Belle II detector.

Semileptonic decays of B mesons provide an important test of the Standard Model (SM) and allow precise determinations of elements of the Cabibbo–Kobayashi–Maskawa (CKM) quark-mixing matrix. In particular, the inclusive decay $B \to X_c \ell \nu$ where $X_c$ denotes any charmed hadronic final state and $\ell = e, \mu$, provides access to the CKM matrix element $|V_{cb}|$, which governs transitions between bottom and charm quarks. Inclusive semileptonic decays are theoretically described using the Heavy Quark Expansion (HQE). In contrast to exclusive measurements, the inclusive approach does not require hadronic form factors for a particular final state. Measurements of the total decay rate and of kinematic moments, including the hadronic invariant mass $M_X$, the squared momentum transfer $q^2$, and the lepton energy or momentum, provide constraints on $|V_{cb}|$ and on the non-perturbative parameters entering the HQE.

The analysis studies inclusive $B \to X_c \ell \nu$ decays using hadronic tagging. One of the two B mesons produced in the event is fully reconstructed as the tag-side B meson, $B_{\text{tag}}$. This allows the properties of the signal-side B meson to be inferred from the remaining particles in the event. After identifying the signal electron or muon, the charmed hadronic system $X_c$ is reconstructed inclusively from the remaining particles. Resolution studies are performed for the main kinematic observables ($p_\ell$, $E_\ell$, $q^2$, $\cos\theta_\ell$), and the effect of final-state radiation on the electron and muon channels is investigated. Migration matrices are constructed to describe how generated quantities are reconstructed at detector level. Together with acceptance and reconstruction efficiencies, these matrices are used to unfold the measured distributions back to generator level. The signal yields are determined using binned maximum-likelihood template fits. The kinematic variables are studied using fits to the hadronic invariant mass $M_X$. Separate templates describe the $B \to X_c \ell \nu$ signal, backgrounds from other B meson decays, and continuum background. A statistical model is implemented using the `pyhf` framework, while `cabinetry` is used for model construction and the fitting workflow. The fitted signal yields are combined with efficiency corrections and migration matrices to obtain unfolded distributions of the measured kinematic variables, which are then used to determine the differential and absolute branching fractions for $B \to X_c \ell \nu$. Both statistical and systematic uncertainties are taken into account. The systematic uncertainties include contributions from branching fractions, charged-particle tracking, tag-side reconstruction efficiency, lepton-identification corrections, and form-factor modeling. Their effects are evaluated using the `SysVar` framework and are incorporated into the statistical model through nuisance parameters. Finally, the measured kinematic moments and the inclusive semileptonic decay rate are used to extract $|V_{cb}|$. The fit is performed with the `Kolya` package, which calculates theoretical predictions for inclusive semileptonic B meson observables within the kinetic scheme. Non-perturbative corrections up to order $1/m_b^3$ and perturbative QCD corrections are included. A correlated chi-squared fit is used to determine $|V_{cb}|$ together with the relevant HQE parameters. The measurements presented provide experimental information for a precise inclusive determination of $|V_{cb}|$ and for further studies of the difference between inclusive and exclusive determinations.