PROCEEDINGS OF SCIENCE

New b-tagging using exclusive b-hadron decays at FCC-ee

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The Future Circular Collider as electron-positron collider (FCC-ee) is planned to produce $O(10^{12})$ $Z \to b\bar{b}$ decays. This means most measurements at the Z-pole will be limited by the systematic uncertainty. This proceedings motivates the use and describes the application of a novel b-quark hemisphere tagger for electroweak precision observables at FCC-ee to reduce systematic uncertainties to the scale of the statistical ones. The tagger uses exclusive b-hadron decays with a potential purity of 100 %, thus being free of c- and light-physics background, which are the main source of systematic uncertainty. Representative b-hadron decay modes are presented and the application of the tagger on the measurement of R_b is highlighted by using simulated samples in an FCC-ee environment.

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1. Introduction

The precise measurement of the hadronic Z-couplings requires the unambiguous determination of the quark-flavour — also to be sensitive to tiny deviations from the Standard Model predictions. The coupling to the b-quark is of special interest with potentially sizeable contributions from new physics. It can be probed with the partial decay width of the Z-boson to b-quarks, defined as

$$R_b = \frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to q\bar{q})}\,, \tag{1}$$

where $\Gamma(Z \to q\bar{q})$ is the hadronic decay width of the Z-boson. The measurement is based on a double-tagging technique of the two hemispheres, defined by the plane perpendicular to the thrust-axis of the event. The counting of the single- and double-tagged hemispheres allows the simultaneous determination of R_b and the b-tagging efficiency ε_b following

$$\begin{aligned} N_b &= 2N_Z \cdot (R_b\varepsilon_b + R_c\varepsilon_c + (1 - R_b - R_c)\varepsilon_{uds}) \\ N_{bb} &= N_Z \cdot (R_b\varepsilon_b^2 C_b + R_c\varepsilon_c^2 C_c + (1 - R_b - R_c)\varepsilon_{uds}^2 C_{uds})\,. \end{aligned} \tag{2}$$

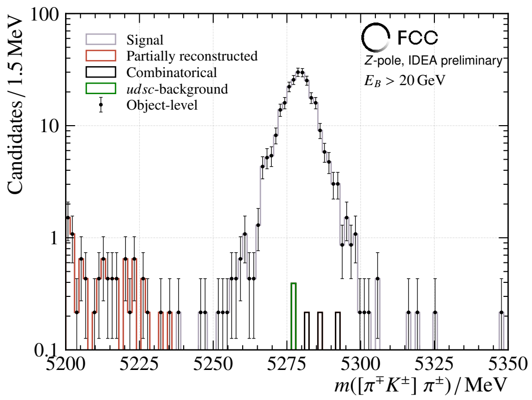
The coefficients C_i are referred to as hemisphere correlations and account for the biases induced in the probe hemisphere by the tagged hemisphere.

While the most precise measurements have been made by the LEP and SLD collaborations, the measurement at a possible FCC-ee (Future Circular Collider as e^+e^--collider) will be limited by the systematic uncertainty due to the event statistics of $\mathcal{O}\left(5 \cdot 10^{12}\right)$ $Z \to q\bar{q}$ decays. About 90 % of the systematic uncertainty budget has its origin in the misidentification the hemisphere quark flavour by applying tagging tools based on the vertex charge or the high-energetic lepton from a semileptonic b-hadron decay [1–3].

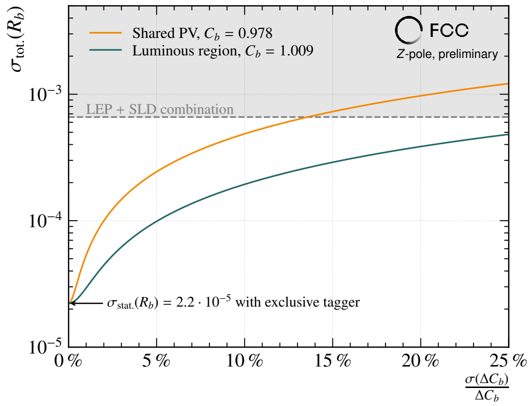
2. New b-flavour tagger

The effective reduction of the systematic uncertainty budget requires an ultra-pure tagging of the quark flavour. This proceedings presents a novel b-flavour tagger based on the exclusive reconstruction of the b-hadron in the event hemisphere with a tagging efficiency of $\varepsilon_b = 1\,\%$ including more than 200 b-hadron decay modes. This results in a statistical precision of $\sigma_{\text{stat.}}(R_b) = 2.2 \cdot 10^{-5}$ (improvement by a factor of about 30 w. r. t. the most precise measurements [1–5]). With state-of-the-art vertex reconstruction, we anticipate that this tagger reaches a potential purity of 100 %, which results in $\varepsilon_c = \varepsilon_{uds} = 0$ in Eq. (2). Hence, the dominating systematic uncertainty is expected to be reduced to the factor C_b, which is determined from Monte-Carlo simulation.

In the following, the purity assumptions are tested by reconstructing six representative modes (varying number of tracks and neutral pions) out of the selected 200 ones. For the sake of this note, only the mode $B^+ \to [K^+\pi^-]_{\bar{D}^0}\,\pi^+$ is presented in further detail. About 40 million centrally produced $Z \to q\bar{q}$ events processed through the IDEA detector concept with DELPHES-fast simulation [6] have been used to evaluate the purity from the invariant-mass spectrum of the b-hadron candidate. The spectrum is shown in Figure 1a with the signal peak shown in grey and the background contribution in green. The combinatorial background and partially-reconstructed components are presented in black and red, respectively. An energy cut on the B^+ candidates of



(a) Mass spectrum in the B^+ signal region highlighting the suppression of background events (green) by up to three orders of magnitude.



(b) The total uncertainty of R_b as function of the relative uncertainty on $\Delta C_b = 1 - C_b$. An effective reduction of the overall uncertainty on ΔR_b becomes possible by the reduction of ΔC_b as well as its respective uncertainty.

Figure 1: Invariant mass spectra for the fully charged decay mode $B^+ \to [K^+\pi^-]_{\bar{D}^0}\,\pi^+$ in Figure a. Figure b highlights the importance of the hemisphere efficiency correlation on the total R_b uncertainty. A cut on the luminous region for candidate reconstruction reduces the correlation and thus improves the precision of R_b.

$E_B > 20\,\text{GeV}$ has been applied to further reduce the background contribution. From this, the purity is calculated to be (99.92 ± 0.12) %, where the contamination from *udsc*-physics originates solely from gluon-splitting into a $b\bar{b}$ pair.

The systematic uncertainty arising from $g \to b\bar{b}$ in $Z \to q\bar{q}$, $q = \{u, d, s, c\}$ has been determined to be subdominant and one order of magnitude less than the uncertainty due to the hemisphere correlation C_b.

3. Systematic uncertainty: hemisphere correlation

The dominant systematic uncertainty affecting R_b comes from the hemisphere correlation C_b. The general impact of the relative uncertainty of $\Delta C_b = 1 - C_b$ on the total uncertainty of R_b is illustrated in Figure 1b for two different values of C_b. The precise knowledge of ΔC_b is instrumental to control the total uncertainty of R_b at the level of the statistical precision. This becomes even more important for values of ΔC_b further away from zero. At LEP times, one of the major sources of C_b departing from one has been identified to be the resolution of the event primary vertex (PV). The knowledge of the luminous region at FCC-ee (beam-spot constraints) has therefore been used to overcome the PV reconstruction uncertainties, which correlates the two hemispheres of an event. The inclusive value has been determined from a set of fully simulated $Z \to b\bar{b} \to [B^+ \to \bar{D}^0\pi^+]_{\bar{b}}[B^- \to D^0\pi^-]_b$ events within the CLD detector [7] to be

$$\Delta C_b^{\text{PV}} = 0.022 \pm 0.003(\text{stat.}) \quad \text{and} \quad \Delta C_b^{\text{Luminous region}} = 0.009 \pm 0.003(\text{stat.})\,. \tag{3}$$

For this, an angular acceptance cut of the thrust-axis of $|\cos(\theta_{\text{Thrust}})| < 0.9$ has been applied and no further source of correlation could be identified in differential evaluations. The uncertainty on ΔC_b stated here is only due to the limited event statistics available but will be at the precision of

1 % with the statistics available in FCC-ee operations. Assuming a realistic total precision of ΔC_b at the 1 %-level with the luminous-region approach, R_b can be measured with a precision of

$$R_b = \mu(R_b) \pm 2.2 \cdot 10^{-5}(\text{stat.}) \pm 1.9 \cdot 10^{-5}(\text{syst.})\,. \tag{4}$$

4. Conclusions

This proceedings has presented the work on a novel b-hemisphere tagger which is based on the exclusive reconstruction of b-hadrons in the hemispheres. This allows to reduce the systematic uncertainty budget to the knowledge of the hemisphere efficiency correlation. This novel tagger can as well be advantageously used to select and tag the quark flavour to measure the b-charge forward-backward asymmetry at the Z pole in order to remove mixing dilutions by accessing the hemisphere charge from B^+ and Λ_b^0 decays.

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