Snowmass2021 - Letter of Interest

[Measurement of R_b in hadronic Z decays at the CEPC]

Thematic Areas: (check all that apply □/■)

□ (EF01) EW Physics: Higgs Boson properties and couplings
□ (EF02) EW Physics: Higgs Boson as a portal to new physics
□ (EF03) EW Physics: Heavy flavor and top quark physics
■ (EF04) EW Precision Physics and constraining new physics
□ (EF05) QCD and strong interactions: Precision QCD
□ (EF06) QCD and strong interactions: Hadronic structure and forward QCD
□ (EF07) QCD and strong interactions: Heavy Ions
□ (EF08) BSM: Model specific explorations
□ (EF09) BSM: More general explorations
□ (EF10) BSM: Dark Matter at colliders
□ (Other) *[Please specify frontier/topical group]*

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Abstract: With an integrated luminosity of 45 ab^{-1} at $\sqrt{s} = 91.2$GeV, more than 10^{12} Z bosons will be produced at the Circular Electron Positron Collider (CEPC). As a real Z boson factory, the precise study of Z boson physics can be achieved. The relative partial width, R_b, of Z boson into b quarks is measured on the CEPC Monte Carlo (MC) level. Based on the latest CEPC detector concept, the Z hadronic decay channel is simulated and reconstructed by the CEPC software framework. By using the double-tagging method, R_b can be solved from several equations referring to the ratios of b-tagged jet hemispheres in Z hadronic events. With the high performance of the b-tagging algorithm for CEPC, the precision of R_b measurement can be improved accordingly.

1 Introduction

The Circular Electron Positron Collider (CEPC) is one of the next-generation e^+e^- colliders, that have been proposed to perform precision measurements of the Higgs boson properties. The CEPC will be hosted in China with a circumference of 100 km and two interaction points(IP)[1]. By operating at $\sqrt{s}$ = 240GeV, the CEPC is expected to produce approximately 10^6 Higgs bosons with an integrated luminosity of 5.6 ab^{-1} in about 7 years. The CEPC will also produce about more than 10^{12} Z bosons in about 2 years with an expected integrated luminosity of 45 ab^{-1} at $\sqrt{s} = 91.2\mathrm{GeV}$[1]. With the high statistics of Z bosons, high-precision electroweak measurements of the Z boson properties can be achieved, such as the R_b measurement.

The relative decay width of $\mathrm{Z} \to \mathrm{b\bar{b}}$ in hadronic Z decays, $R_b = \Gamma(\mathrm{Z} \to \mathrm{b\bar{b}})/\Gamma(\mathrm{Z} \to \mathrm{hadrons})$, is a sensitive electroweak parameter to test the Standard Model (SM) and find new physics[2–4]. For example, the existence of stop-quarks or charginos in supersymmetry can result in a deviation between the measured R_b and the one in the SM[5]. The LEP and SLD collaborations have made accurate measurements of the R_b[6–10] with a combined value of $R_b = 0.21629 \pm 0.00066$[11]. The measurement of R_b at the CEPC is expected to be more precise owing to its high statistics of the Z boson and high performance of the b-tagging.

2 Monte Carlo simulation

The CEPC conceptual detector, following the Particle Flow Algorithm (PFA)[16], is composed of a silicon pixel vertex detector, a silicon tracking system, a TPC, an electromagnetic calorimeter and a hadronic calorimeter. The latest version of the conceptual detector is CEPC_v4[1], which has been updated and optimized from the preliminary conceptual detector CEPC_v1[17]. More information about the studies on the conceptual detector can be found in Ref.[18–22].

The Monte Carlo particles are generated from physics models by using Whizard[12] at the parton level and then interfaced with Pythia[13] for hadronization simulation. The MC particles are simulated by the detector simulation framework MokkaPlus[14] based on Geant4[15]. MokkaPlus is a simulation framework used for linear colliders and has been updated to match the CEPC detector concept.

The final physics objects, such as the lepton, photon and jet, are reconstructed by using a dedicated particle flow reconstruction framework Arbor[23;24]. A final state classification framework, FSClasser[25], is used for the reconstruction of the final physics events.

3 Analysis method

The R_b measurement is based on the double-tagging method. The procedure of the method is described as follows: The jets in the hadronic decay events are divided into two kinds of hemispheres, namely, hemisphere I and hemisphere J, according to the plane perpendicular to the thrust axis. By applying the b-tagging cuts on the two hemisphere samples separately, we can then retrieve two b-tagged hemispheres. The number of b-tagged hemisphere I samples is named N_t^I. For the opposite hemisphere J, the number of tagged samples is named N_t^J. For the two kinds of hemispheres, the b-tagging cut points can be applied differently. The number of events in which both hemispheres are tagged can be counted as $N_{tt}^{I,J}$. Three equations can be written out according to the b-tagged hemispheres ratios in all Z hadronic events (N_{had}):

$$\begin{aligned}\frac{N_t^I}{N_{had}} &= \epsilon_b^I R_b + \epsilon_c^I R_c + \epsilon_{uds}^I (1 - R_b - R_c) \\ \frac{N_t^J}{N_{had}} &= \epsilon_b^J R_b + \epsilon_c^J R_c + \epsilon_{uds}^J (1 - R_b - R_c) \\ \frac{N_{tt}^{I,J}}{N_{had}} &= \epsilon_b^I \epsilon_b^J C_b R_b + \epsilon_c^I \epsilon_c^J C_c R_c + \epsilon_{uds}^I \epsilon_{uds}^J C_{uds} (1 - R_b - R_c)\end{aligned} \tag{1}$$

where ϵ_b^I, ϵ_c^I, and ϵ_{uds}^I are the b-tagging efficiencies for hemisphere I in $\mathrm{Z} \rightarrow \mathrm{b\bar{b}}$, $\mathrm{Z} \rightarrow \mathrm{c\bar{c}}$ and $\mathrm{Z} \rightarrow \mathrm{uds}$. The ϵ_b^J, ϵ_c^J, and ϵ_{uds}^J are the b-tagging efficiencies for hemisphere J in those Z boson decay channels. The C_b, C_c and C_{uds} are the b-tagging correlation factors between the two jet hemispheres in the three hadronic decay channels. The correlation factor in $\mathrm{Z} \rightarrow \mathrm{b\bar{b}}$ is computed by: $C_b = \epsilon_{bb}/(\epsilon_b^I \epsilon_b^J)$, where ϵ_{bb} is the efficiency that both jets are tagged. The uncertainty in C_b is one of the main systematic errors in the R_b measurement. As the efficiencies of both jets tagged in $\mathrm{Z} \rightarrow \mathrm{c\bar{c}}$ and $\mathrm{Z} \rightarrow \mathrm{uds}$ are very small, the effect of C_c and C_{uds} can be ignored for systematic errors. ϵ_c^I, ϵ_{uds}^I, ϵ_c^J, ϵ_{uds}^J, C_b, C_c and C_{uds} are retrieved from the MC samples. N_{had}, N_t^I, N_t^J, and $N_{tt}^{I,J}$ are measured from real data of Z hadronic decays. Based on Eq.(1), the three unknown values ϵ_b^I, ϵ_b^J and R_b can be solved.

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