Snowmass2021 - Letter of Interest

Probing new physics with the measurements of $e^+e^- \to W^+W^-$ at CEPC with optimal observables

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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Collaboration (optional):

Authors: (long author lists can be placed after the text)

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Abstract: (maximum 200 words)

We propose to study the prospectives of the diboson ($e^+e^- \to W^+W^-$) measurements at the CEPC in the effective-field-theory framework. We plan to implement the method of optimal observables to extract useful information in the differential distributions and obtain the best possible reach on the coefficients of the corresponding dimension-six operators. The impact of systematic uncertainties due to detector resolutions and beamstrahlung effects will be thoroughly investigated.

1 Background

The Circular Electron Positron Collider (CEPC) is a proposed future lepton collider based in China[1]. With runs at the Z-pole, WW threshold and around 240 GeV, it can reach unprecedented precisions for the measurements of the Higgs boson and the electroweak gauge bosons. For the electroweak gauge boson, the future prospectives of the measurements at the Z-pole and the WW threshold have already been studied in the conceptual design report[1]. Meanwhile, there is no projection for the set of observables in the diboson process, $e^+e^- \to W^+W^-$, at the CEPC. These observables are conventionally parameterized in terms of the anomalous triple Gauge couplings (aTGCs), and can be well measured at energies above the WW threshold, such as 240 GeV. They contain important information on the properties of the electroweak gauge bosons and provide crucial inputs for global effective-field-theory (EFT) analyses. A recent study[2] pointed out the importance of implementing the full EFT parameterization instead of the conventional three aTGC parameterization for the diboson process at future lepton colliders, and demonstrated the usefulness of the so-called *optimal observables*[3] for extracting information in the differential distributions of the diboson events. However, due to the absence of experimental inputs, Ref.[2] only performed a simplified diboson analyses based on statistical uncertainties. A more realistic analysis, which takes account of the systematics and detector effects, is desired to fully understand the potential of CEPC in probing the EFT parameters in the diboson measurements.

2 Proposed Study

We plan to focus on the semi-leptonic decay channel of the $e^+e^- \to W^+W^-$ process, which has a sizable branching fraction and good event reconstructions. While the optimal observable analysis in Ref.[2] gives an estimation on the precision reaches of the corresponding EFT parameters, our main focus will be on the investigation of the impacts of systematic uncertainties. This is a nontrivial task given the complicated nature of the optimal observables and their sensitivity to the differential distributions. In particular, the optimal observables at the parton level may be significantly different from those at detecter level, if the 4-momenta of the final state particles are not very well reconstructed. As such, it is important to understand the impacts of the resolutions of the jet energy and momentum, as well as the reconstruction of the missing momentum of the neutrino.

Our first step would be to compare the parton level and detector level results of the optimal observable analyses and understand the impact of systematics in terms of both the reconstructed central values of the EFT parameters (*i.e.* whether a bias can be induced by the systematics) and their uncertainties. In this comparison, we will also study the impacts of the selection cuts, such as the requirements on invariant mass that ensures the correct reconstruction of the W boson, on reducing the systematic uncertainties on the optimal observables. If the impacts of systematics are large and difficult to remove with selection cuts, we will also explore on the use of more sophisticated methods, such as machine learning techniques to estimate the precision reach on the EFT parameters and compare those with the ideal reach from the optimal observables.

3 Outlook

Our results on the optimal observable analyses of the diboson measurements will serve as a crucial component of a realistic global EFT analyses at the CEPC. It is also possible to generalize our analysis to include other decay channels of the diboson process in order to use all the available events. Furthermore, the methods we develop may also be applicable to other measurements at the CEPC for extracting information in the differential distributions.

References

[1] **CEPC Study Group** Collaboration, M. Dong et al., *CEPC Conceptual Design Report: Volume 2 - Physics & Detector*, arXiv:1811.10545.

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[3] M. Diehl and O. Nachtmann, *Optimal observables for the measurement of three gauge boson couplings in* $e^+e^- \to W^+W^-$, *Z. Phys. C* **62** (1994) 397–412.

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