Snowmass2021 - Letter of Interest

Exclusive Z decays

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
■ (RF8) Weak decays of the Z boson

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Abstract: (maximum 200 words)

Exclusive hadronic Z decays, such as $Z \to M\gamma$ and $Z \to MM'$ with $M^{(\prime)}$ being a meson, play an important role in decisively testing the QCD factorization theorems, and cleanly probing the inner structures of the involved mesons. The key point is that the power corrections of $\mathcal{O}(\Lambda^n_{\rm QCD}/M^n_Z)$ can be safely neglected. Future Tera-Z factories will have a good chance to measure many such channels (*e.g.* $Z \to J/\psi\gamma, \rho\gamma$ have $\mathcal{O}(10^{-9} - 10^{-8})$ branching ratios), which will be helpful for deeper understanding of QCD and hadronic structures. We propose to study important exclusive channels theoretically in more details, and also to study experimentally the corresponding detector performance requirement to achieve the physical goals.

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Proposed future lepton colliders, the CEPC[? ?] and the $\mathrm{FCC_{ee}}$, are both expected to collect a data sample containing about 10^{12} Z events at the Z mass pole. This will make it promising to discover many exclusive hadronic Z decays. According to previous theoretical studies[? ?], radiative decays such as $Z \to J/\psi\gamma, \rho\gamma$ can have branching ratios of $\mathcal{O}(10^{-9})$ to $\mathcal{O}(10^{-8})$, so they will for sure get precisely measured. Even non-leptonic channels like $Z \to \pi^+\pi^-, K^+K^-$ are hopeful to be touched at future Tera-Z factories[?]. Other types of exclusive decays including weak-radiative decays and semi-leptonic decays can also be studied.

Exclusive hadronic Z boson decays will provide an ideal platform for test of QCD factorization formalisms for exclusive decays[? ? ? ?]. Although the QCD factorization formalisms are originally invented for and widely applied in studies of exclusive B meson decays, they suffer from pollution from large power corrections of $\mathcal{O}(\Lambda^n_{\rm QCD}/m_b^n)$, since the b quark mass is not large enough. While, in most radiative Z boson decays, the typical characteristic energy scale is around the Z mass, and thus the power corrections of $\mathcal{O}(\Lambda^n_{\rm QCD}/m_Z^n)$ can be safely neglected. In this sense, the factorization formalisms can be clearly examined at leading power by exclusive hadronic Z decays, once they get measured at the CEPC to some precision.

Moreover, the radiative $Z \to M\gamma$ channels can be used to explore information of the internal structures of the involved light mesons, say, the light-cone distribution amplitudes (LCDAs), which are essential inputs to factorization calculations of the meson involved processes. Unlike the parton-distribution function of the proton precisely determined by high-energy inclusive processes, a similar comprehensive experimental determination of meson LCDAs has always been absent. Owing to the strong suppression of higher-power suppressions, it will be feasible to extract the corresponding leading-twist meson LCDAs from the $Z \to M\gamma$ measurements.

We propose to study these exclusive Z decays theoretically, especially via the factorization formalisms. We plan to calculate the branching ratios of more non-leptonic decay channels. Radiative corrections will be calculated, which are always necessary for precision studies. We also propose to study the experimental details of measuring some important decays channels, including event reconstruction and possible background. The objective is to determine the requirements of the facility performances in order to achieve the above physical goals.

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