News on the physics potential of the reaction $e^+e^- \rightarrow Z\gamma$

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The next large project in particle physics is widely expected to be a high-energy electron-positron collider. Such a facility could be realised as a circular collider, like the Circular Electron Positron Collider (CEPC) and the Future e^+e^- Circular Collider (FCC-ee) [1], or as a linear collider, like the International Linear Collider (ILC) and the Compact Linear Collider (CLIC) [2]. Besides the direct observation of new phenomena making use of the clean experimental environment in electron-positron collisions, the precision study of Standard Model (SM) processes provides an important tool to search for new physics at these colliders.

A recent study of $e^+e^- \rightarrow Z\gamma$ scattering [3] illustrates the sensitivity of this process in the energy range of the colliders mentioned above using the framework of Standard Model Effective Field Theory (SMEFT). The authors have constructed and investigated dimension-8 operators which are related to neutral Triple Gauge Couplings (nTGC). In particular, the presented pure gauge operators are shown to contribute to the $Z\gamma Z^*$ and $Z\gamma\gamma^*$ vertices. Due to a strong energy dependence, these vertices can be probed well in $e^+e^- \rightarrow Z\gamma$ events at high energy. The resulting sensitivities to new physics scales are obtained using $Z \rightarrow q\bar{q}$ decays. These findings extend earlier work which was focused on dimension-8 operators related to the SM Higgs doublet and considering $Z \rightarrow \ell^+\ell^-$ decays [4].

Figures 3-6 of ref. [3] show the individual impact of four dimension-8 operators, including the two pure gauge operators O_{G+} and O_{G-} , on the azimuthal angle ϕ_* as defined in

Figure 1 of the same paper. The dominant contribution to the new physics sensitivities arises from interference terms of the order $O(\Lambda^{-4})$, where Λ is the scale of new physics. Figure 8 shows the reach for the new physics scales of the four investigated dimension-8 operators as functions of the centre-of-mass energy of the collider. For all considered colliders, the new physics sensitivity extends to scales far beyond their centre-of-mass energy. Assuming a constant integrated luminosity, the new physics reach rises strongly with the centre-of-mass energy. This assumption is conservative for linear colliders, where the achievable integrated luminosity increases with the energy. The dependence of the results on the event selection efficiency is found to be small while longitudinal beam polarisation can provide typical improvements on the level of 20% on the new physics scales. Finally, correlations of pairs of the four considered dimension-8 operators are shown in Figure 9.

The obtained sensitivities demonstrate that the $e^+e^- \rightarrow Z\gamma$ process provides complementary information on dimension-8 operators compared to other probes. This strongly motivates detailed studies based on realistic detector simulations and including initial-state radiation (ISR) and beam-beam effects by the experimental collaborations for the various colliders. The measurement of angular observables from hadronic Z decays could serve as an interesting benchmark for the optimisation of detector concepts and jet reconstruction techniques, in particular at the highest possible energies. For instance, the approach discussed in ref. [5] for HZ production at the 3 TeV CLIC stage might be applied here. The strong gain in

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the sensitivity to new physics scales with the centre-of-mass energy suggests that the $e^+e^- \rightarrow Z\gamma$ process is also very relevant in view of lepton collider options that could reach even higher energies, such as a linear collider using novel accelerator techniques or a muon collider.

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