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Electroweak couplings of the boson at CLIC

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Abstract

To be written

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First studies of boson precision measurements at CLIC are described in this document in response to a request by the ECFA Higgs@FutureColliders working group. Projections for a dedicated energy stage at the pole are summarised in Sec. 1 while Sec. 2 describes the potential of radiative return events at a 380 GeV CLIC collider.

1 Z-pole operation

A dedicated CLIC stage at the pole has not been studied in detail yet and is not considered as a part of the baseline CLIC programme. First estimates of the physics performance for measurements of the EW couplings of the boson are given here.

We assume that a dedicated CLIC stage at the Z pole would provide an integrated luminosity of $100\,\mathrm{fb}^{-1}$ in a few years of operation. The electron beam polarisation is expected to be $\pm 80\%$.

In this section, we assume a 50:50 splitting of the -80% and +80% polarisation configurations. In total, this program would provide 4.5 billion bosons including about 3 billion decays in hadronic decay modes.

It is expected that the polarisation of the electron beam can be measured with 0.1% precision using polarimeters upstream and downstream of the interaction point.

1.1 Asymmetry parameters

Using electron beam polarisation, CLIC can measure the left-right asymmetry:

$$A_{LR} = \frac{1}{|P|}\frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = A_e. \tag{1}$$

Using hadronic decays of the boson, the measurement would be dominated by systematic uncertainties. The uncertainty on the beam polarisation can be directly propagated to the uncertainty of A_{LR}:

$$\frac{\Delta A_{LR}}{A_{LR}} = \frac{\Delta P}{P}. \tag{2}$$

The value of A_{LR} is also sensitive to the collision energy, e.g. for hadronic final states [**Irles:2019xny**]:

$$dA_{LR}/d\sqrt{s} \approx 2 \times 10^{-5}/\,\mathrm{MeV}. \tag{3}$$

To achieve a precision better than the uncertainty due to the polarisation measurement, the collision energy needs to be controlled to a few MeV. It is expected that a precision of about 1 MeV can be achieved using the reaction → due to the excellent tracking resolution of the CLIC detector [**wilson_calib**, **jjb_calib**].

In addition, a beam energy spread of several per mille is expected. It remains to be demonstrated that the shape of the beam energy distribution can be reconstructed with sufficient precision.

For the other fermions, the combined left-right forward-backward asymmetries are used:

$$A^f_{FB,LR} = \frac{1}{P}\frac{(\sigma_F - \sigma_B)_L - (\sigma_F - \sigma_B)_R}{(\sigma_F + \sigma_B)_L + (\sigma_F + \sigma_B)_R} = \frac{3}{4}A_f. \tag{4}$$

We find that the systematic uncertainties on A, A, A, A_c and A_b are dominated by the 0.1 % uncertainty on the electron beam polarisation. The statistical precisions were estimated assuming tagging efficiencies for b- and c-jets of 80% and 50%, respectively. Only hadronic decays of the tau leptons were considered. The resulting precisions are summarised in Tab. 1.

Observable	PDG value [**Tanabashi:2018oca**]	$\Delta_{stat.}$	$\Delta_{syst.}$
A	0.1515	0.00002	0.00015
A	0.142	0.00014	0.00014
A	0.143	0.00021	0.00014
A_c	0.670	0.00013	0.00067
A_b	0.923	0.00007	0.00092

Table 1: Projectd uncertainties on the polarisation asymmetries assuming $100\,\text{fb}^{-1}$ collected at $\sqrt{s} =$ 91 GeV. The values for all observables are taken from the Particle Data Group.

Observable	PDG value [**Tanabashi:2018oca**]	$\Delta_{stat.}$	$\Delta_{syst.}$
$1/R$	0.0481	4×10^{-6}	2×10^{-5}
$1/R$	0.0481	4×10^{-6}	1×10^{-5}
$1/R$	0.0482	6×10^{-6}	2×10^{-5}
R_c	0.172	1.5×10^{-5}	4×10^{-4}
R_b	0.216	1.1×10^{-5}	1.5×10^{-4}

Table 2: Projected uncertainties on the decay ratios assuming $100\,\text{fb}^{-1}$ collected at $\sqrt{s} = 91$ GeV. The values for all observables are taken from the Particle Data Group.

1.2 Decay ratios

The decay ratios are defined as:

$$R_{,} = \frac{\Gamma(\to,)}{\sum_{=,,,,}\Gamma(\to)} \text{ and} \tag{5}$$

$$R_{,,} = \frac{\sum_{=,,,,}\Gamma(\to)}{\Gamma(\to,,)}. \tag{6}$$

The systematic uncertainties from the total luminosity and beam polarisation cancel in these ratios. The flavour tagging capabilities of the SLD detector are more similar to the detctor concept developed for CLIC compared to the LEP experiments. The systematic uncertainties on the measurements of R_b and R_c at SLD are summarised in Tab. 7 of [**Abe:2005nqa**]. Many of the uncertainties are related to the properties of charmed and beauty hadrons which will be much better known at the time of CLIC operation. Other uncertainties are limited by finite sizes of the SLD MC samples. We assume conservatively that the overall systematic uncertainties of the SLD measurements can be improved by a factor 5 at CLIC.

Tab. 2.2 of [**ALEPH:2005ab**] summarises the systematic uncertainties on the , , pair production cross sections at LEP. The dominant contribution is due to the understanding of the detector acceptance. We assume here that these effects scale with the integrated luminosity.

Projections for the statistical and systematic uncertainties on the decay ratios are summarised in Tab. 2.

2 Return-to Z events at $\sqrt{s} = 380$ GeV

The first centre-of-mass energy stage in the current CLIC baseline scenario [**Robson:2018zje**] is foreseen at $\sqrt{s} = 380$ GeV. The expected integrated luminosity is $1\,\text{ab}^{-1}$, equally split between the -80% and +80% electron beam polarisation configurations. The electron beam polarisation can be measured using two complementary approaches: polarimeters as described in Sec. 1 or from the $\to$ process [**Monig:2004jc**].

Observable	PDG value [**Tanabashi:2018oca**]	$\Delta_{stat.}$	$\Delta_{syst.}$
A	0.1515	0.0006	0.00015
A	0.142	0.0039	0.00014
A	0.143	0.0055	0.00014
A_c	0.670	0.0019	0.00067
A_b	0.923	0.0036	0.00092

Table 3: Projected uncertainties on the polarisation asymmetries assuming $1\,\text{ab}^{-1}$ collected at $\sqrt{s} =$ 380 GeV. The values for all observables are taken from the Particle Data Group.

Both methods are expected to provide an accuracy of 0.1%. Hence the polarisation measurement for a potential run at 91 GeV relying solely on the polarimeters could be validated at 380 GeV.

The energy loss due to the ISR and beamstrahlung effects provides large samples of return-to- events at the 380 GeV energy stage. In particular, significant improvement with respect to LEP and SLC is expected on the A_e asymmetry parameter. In the following, we discuss first estimates for the observables introduced in Sec. 1 at 380 GeV. The results are based on events generated using the Whizard 2 package [**Moretti:2001zz**, **Kilian:2007gr**]. Cuts are applied to simulate the geometric acceptance of the CLIC detector and to suppress backgrounds from photon-photon and photon-electron interactions. For example, more than 3.5 million hadronic boson decays pass the event selection.

2.1 Asymmetry parameters

All asymmetry parameters are subject to a systematic uncertainty of 0.1% from the measurement of the electron beam polarisation. A detailed study of the charge reconstruction for b- and c-jets is necessary to understand the corresponding uncertainties, which we leave for future investigation. The projected statistical and systematic uncertainties are summarised in Tab. 3.

2.2 Decay ratios

In addition to the reconstruction of visible decays, the 380 GeV stage also allows to identify $\rightarrow$ events using hard ISR photons. We define the following ratio that provides information on the neutrino couplings of the boson:

$$R = \frac{\Gamma(\rightarrow)}{\sum_{=,,,,}\Gamma(\rightarrow)}. \tag{7}$$

The measurements of the decay ratios require an excellent understanding of the reconstruction efficiencies for charged leptons, photons and heavy-quark jets. For illustration, we assume systematic uncertainties of 0.1% for final states with electrons, muons, photons and b-jets, and 0.5% for final states with tau leptons and c-jets here. Projections for the statistical and systematic uncertainties are summarised in Tab 4.

2.3 Other relevant measurements at $\sqrt{s}$ = 380 GeV

The 380 GeV stage allows to determine the boson mass with a precision of about 2.5 MeV [**Baak:2013fwa**].

References

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Observable	PDG value [**Tanabashi:2018oca**]	$\Delta_{stat.}$	$\Delta_{syst.}$
$1/R$	0.0481	0.00012	0.00005
$1/R$	0.0481	0.00012	0.00005
$1/R$	0.0482	0.00016	0.00024
R_c	0.172	0.00042	0.00086
R_b	0.216	0.00031	0.00022
R	0.286	0.0027	0.00029

Table 4: Projected uncertainties on the decay ratios assuming 1 ab^{-1} collected at $\sqrt{s} = 380$ GeV. The values for all observables are taken from the Particle Data Group.

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