The need of polarimetry for GigaZ

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GigaZ offers the possibility to measure the weak mixing angle $\sin^2\theta_{\rm eff}^\ell$ with unprecedented precision [1]. An improvement of more than an order of magnitude relative to LEP/SLD will be possible It has been shown e.g. in the MSSM that one can obtain significant new information about model parameters using this quantity that might not be accessible otherwise because the involved thresholds are beyond the ILC energy range [2, 3]. GigaZ requires only minor modifications to the machine and needs a running time of only about one year. It is essential to keep this option open during the lifetime of the ILC. Further details have been given elsewhere [4].

With polarized beams the weak mixing angle $\sin^2\theta_{\rm eff}^\ell$ can be measured from the left-right cross-section asymmetry:

$$\begin{aligned} A_{\rm LR} &= \frac{1}{\mathcal{P}}\frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \\ &= \mathcal{A}_{\rm e} \\ &= \frac{2 v_e a_e}{v_e^2 + a_e^2} \\ v_e/a_e &= 1 - 4\sin^2\theta_{\rm eff}^\ell \end{aligned} \tag{1}$$

independent of the final state. With 10^9 Zs, an electron polarization of 80% and no positron polarization the statistical error is $\Delta A_{\rm LR} = 4\cdot 10^{-5}$. The error from the polarization measurement is $\Delta A_{\rm LR}/A_{\rm LR} = \Delta\mathcal{P}/\mathcal{P}$ and will be much larger than the statistical error.

If electron and positron polarization are available the total cross section is given by

$$\sigma \;=\; \sigma_u\left[1 - \mathcal{P}_{\rm e^+}\mathcal{P}_{\rm e^-} + A_{\rm LR}(\mathcal{P}_{\rm e^+} - \mathcal{P}_{\rm e^-})\right] \tag{2}$$

If all four helicity combinations are measured $A_{\rm LR}$ can be determined as

$$A_{\rm LR} \;=\; \sqrt{\frac{(\sigma_{++}+\sigma_{-+}-\sigma_{+-}-\sigma_{--})(-\sigma_{++}+\sigma_{-+}-\sigma_{+-}+\sigma_{--})}{(\sigma_{++}+\sigma_{-+}+\sigma_{+-}+\sigma_{--})(-\sigma_{++}+\sigma_{-+}+\sigma_{+-}-\sigma_{--})}} \tag{3}$$

An absolute polarization measurement is no longer needed with this scheme. This allows for a substantial gain in precision. With $\mathcal{P}_{\rm e^-} = 80\%$ and $\mathcal{P}_{\rm e^+} = 60\%$

the error on $\sin^2\theta^\ell_{\rm eff}$ can be decreased by an order of magnitude compared to the current value. However, beam polarimetry is still required for two reasons:

- Eq. 3 assumes exactly equal magnitudes for the left and right handed polarization states. This has to be verified or a correction has to be derived from polarimetry. Any difference needs to be measured to very high accuracy of $\delta(\mathcal{P}_L - \mathcal{P}_R) < 10^{-4}$ which requires excellent statistical performance without significant background fluctuations and a high degree of redundancy of the polarimeter.

- In eq. 2 the polarization comes in a linear term and as the product of the two beam polarizations. For that reason the measurement is sensitive to correlated changes in the electron and positron polarization. These can be variations over time or inside a train. To monitor and measure such effects calls for fast and stable polarimetry. If one assumes that the polarization is 2% larger than the average for one half of the luminosity and 2% smaller for the other half, the corresponding shift in $A_{\rm LR}$ will be equal to the statistical error. This effect scales with the square of the variation.

While this scheme does not require absolute beam polarization input, it still needs polarimeters with excellent statistical performance, very low background and good stability for precise relative measurements at the level of 10^{-4} or better. Apart from the knowledge of the analyzing power, none of the polarimeter requirements can be significantly relaxed in order to achieve the full potential of the GigaZ program.

References

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