Measurement of A_{LR} using radiative return at ILC 250

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At a polarized e^+e^- collider, A_e is given by the left-right asymmetry A_{LR} in the total rate for Z production,

$$A_e = A_{LR} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}, \tag{1}$$

where σ_L and σ_R are the cross section for 100% polarized $e^-_L e^+_R$ and $e^-_R e^+_L$ initial states. This A_{LR} is important for the electroweak study, and can provide a very useful constraint for operators c_{HL}, c'_{HL}, and c_{HE} in the global SMEFT fit [1][2][3][4].

It turned out that the precision of the A_{LR} measurement done at SLC, being at around 1%, is not good enough for the global fit. It is hence motivated to improve this observable at the ILC.

At the ILC250, we can use the radiative return process, $e^+e^- \to \gamma Z$, to measure the A_{LR}. We can tag the signal events using just the polar angles of the two fermions from $Z \to ff$. To describe the method simply, we will use the approximations that the fermions are massless and the photon is collinear to the beam directions. This is already quite close to realistic, and the approximations can be relaxed with small corrections. Then let E_i and θ_i, $i = 1, 2$, denote the energy and polar angle, respectively, of each final lepton or jet. Transverse momentum conservation implies that $E_1 sin\theta_1 = E_2 sin\theta_2$. The fermion pair is boosted only in the beam direction. The boost factor can be determined as

$$|\beta| = \frac{|E_1 cos\theta_1 + E_2 cos\theta_2|}{E_1 + E_2} = \frac{|sin(\theta_1 + \theta_2)|}{sin\theta_1 + sin\theta_2}. \tag{2}$$

It is interesting that the E_i cancel out, so β only depends on θ_1 and θ_2. The invariant mass of the fermion pair, m_{12}, can then be reconstructed as

$$m_{12}^2 = \frac{1 - |\beta|}{1 + |\beta|} \cdot s, \tag{3}$$

where $\sqrt{s}$ is the center-of-mass energy. For the signal events we expect that m_{12} peaks at m_Z and, for $\sqrt{s} = 250$ GeV, $|\beta|$ peaks at 0.76. The angles θ_1 and θ_2 can be measured very precisely at the ILC detectors, so that the signal events can be tagged without the need to observe the ISR photon. This method was actually used at LEP2 [5], though mainly for calibrating the beam energy due to the limited statistics. But at ILC250, we will expect 90 millions of such radiative events, a factor of 5 (100) more than the total number of Z produced at LEP (SLC).

There is a fast detector simulation study available for this reaction [6]. We would like to perform full detector simulation study to get more realistic estimations including systematic errors. There were 2 dominant systematic errors: uncertainty of beam E_{CM} and uncertainty of beam polarization in current best measurement of A_{LR} (SLD), which is 0.1514±0.0019 (statistic error)±0.0011(systematic error) [7]. We would like to access how much we can improve these systematic errors. At the ILC250, the determination of the beam polarization can be helped using $e^+e^- \to WW$ process. Nominal E_{CM} is far away from the di-fermion invariant mass and hence the sensitivity of A_{LR} to the E_{CM} is expected to be significantly less. We are also interested in theory errors from higher order calculation of $e^+e^- \to \gamma Z$ in terms of A_{LR} measurement.

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