

Impact of polarized e^- and e^+ beams at a future Linear Collider and a Z-factory

Part I – Fundamentals in polarization and electroweak precision physics

Gudrid Moortgat-Pick

University of Hamburg, Luruper Chaussee 149, 22761 Hamburg and DESY, Notkestrasse 85, 22607 Hamburg

E-mail: gudrid.moortgat-pick@desy.de

Abstract. The main goal of new physics searches at a future Linear Collider is the precise determination of the underlying new physics model. The physics potential of the ILC as well as the multi-TeV option collider CLIC have to be optimized with regard to expected results from the LHC. The exploitation of spin effects plays a crucial role in this regard. After a short status report of the Linear Collider design and physics requirements, this article explains fundamentals in polarization and provides an overview of the impact of these spin effects in electroweak precision physics. The gain of polarized beams in physics searches beyond the Standard Model, however, is summarized in part II [1].

1. Introduction

Although the Standard Model has been successfully tested in precision experiments at LEP and SLC up to the quantum level, there are still some substantial open questions and shortcomings as, for instance,

- the establishment of the electroweak symmetry breaking
- the solution to the instability of the Higgs boson mass with regard to large quantum corrections ('hierarchy problem')
- an explanation of the existing baryon asymmetry in the Universe
- the composite of dark matter
- an unification of the electroweak and strong forces at high energy.

Therefore a strong believe in physics beyond the Standard Model exists. In most cases the interesting energy range to resolve these physics questions is expected around the TeV scale since the hierarchy between the mass of the 'electroweak' and the 'Planck' scale can still be protected for new physics turning up at the TeV scale. Further motivation for the envisaged energy range comes from cosmology that predicts that dark matter candidates are consistent with sub-TeV scale weakly interacting massive particles ('WIMPs').

Important experimental results are expected in the near future by results from hadron colliders at the high energy frontier, the Tevatron and the recently started LHC complemented

by experiments from neutrino- and astroparticle physics. However, a clear enlightening of the structure of the underlying physics is only expected with data from a —currently in the design phase— Linear Collider (LC).

Due to the clean experimental environment at a Linear Collider, unique high precision measurements are expected that allow to determine the properties of new physics particles with unprecedented accuracy.

Spin properties play also a crucial role in this context and can be successfully exploited at a LC in all steps of such particles processes, from production up to the final state cascades, providing different insights in physics, respectively:

initial polarized $e^+e^- \longrightarrow$ intermediate fermions/bosons \longrightarrow final states: quarks and leptons.

Beam polarizations of the initial particles provide access to the chirality and the interaction structure of the production processes; the spin correlations between production and decay processes provide access to the spin properties of the intermediate particles (fermions as well as bosons), and the spin of the final particles can be particularly well exploited to study properties of 3rd family fermions as top quarks and tau leptons.

The physics return from the investment in a linear collider would be maximized by the possibility of providing both initial beams, electron as well as positron, polarized with a high degree of polarization and without a significant loss in luminosity. A polarized electron beam would already provide a valuable tool for stringent tests of the Standard Model and for diagnosing new physics. However, the full potential of the linear collider could be realized only with a polarized positron beam as well. In addition to enabling more detailed studies of directly accessible new particles and a precise analysis of their interaction properties, it would also strongly improve indirect searches for new physics.

2. The future Linear Collider: features and requirements

Contrary to hadron colliders as, for instance the LHC and the Tevatron, where composite particles (p) are brought into collisions, the initial particles at a Linear Collider can be regarded as being point like. Therefore a precisely known centre-of-mass energy is provided, that is in addition also easily tunable. The envisaged energy of the future Linear Collider is $\sqrt{s} = 500$ GeV up to 1 TeV. Although a very high luminosity is provided at a LC, practically all events in the detector can be analyzed due to the clean experimental environment and no triggers have to be applied. This differs from physics analyses at the LHC, where multiple triggers are required and only a small fraction of events can really be analyzed in the detector. Shortly speaking, due to the higher cms energy of about \sqrt{s} (10) TeV, the LHC opens mainly a new high energy frontier, whereas the LC will provide access to a new precision frontier.

Such a high precision potential is a unique advantage: the measurements become so accurate that one is even sensitive to contributions of virtual particles, that means contributions of not directly accessible particles at the quantum level. Therefore effects of still undiscovered particles, but whose properties are well defined by the theory, become visible. Such a sensitivity enables both discoveries of new physics effects and their underlying structure as well as consistency checks of the Standard Model.

In order to fulfill these physics goals, the machine requirements have been worked and clearly defined, see [2]:

- A full luminosity of not less than $\mathcal{L} = 2 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$.
- The beam stability and precision should be below a tenth of a percent level.
- The machine interface must allow measurements of the beam energy and the differential luminosity spectrum with also a precision of below a tenth of percent level.

- A polarization of the e^- beam of at least 80% within the whole energy range.
- An optional polarization of the e^+ with at least 50% without causing a significant loss of luminosity. In order to use polarized beams in an optimal manner helicity reversals between bunch crossings are desirable.
- An optional high luminosity run at the Z-pole and the WW threshold ('GigaZ option'). The precision requirements are at this energy stage even more demanding than at the high energy: simultaneous e^- and e^+ polarization under application of frequent helicity flips are mandatory. The energy stability and calibration accuracy should still be below a tenth of a percent level.

Both for the International Linear Collider (ILC) as well as for the multi-TeV CLIC design option these requirements have to be fulfilled and are rather challenging from experimental point of view.

Whereas the ILC feasibility is agreed and its final design is on a mature R&D level, the CLIC option still lacks the proof of feasibility and several technical issues are still under discussion.

3. Polarized lepton beams at high energy colliders

Polarization is defined as the ensemble of particles with definite helicity $\lambda = -\frac{1}{2}$ left- or $+\frac{1}{2}$ right-handed:

$$P = \frac{\#N_R - \#N_L}{\#N_R + \#N_L}$$

Since the initial leptons can be regarded as being mass less, the helicity corresponds to their chirality.

It is well known that one can get transversely polarized beams at circular accelerators due to the spin-flip process caused via synchrotron radiation (the so called Sokolov-Ternov effect). This was successfully demonstrated at HERA, where an excellent e^\pm polarization of about 50%–70% was achieved, depending also on the numbers of spin rotators before and after the interaction points required to generate longitudinally polarized beams for physics studies.

At LEP, however, massive depolarization effects were dominant. Therefore the (low) produced polarization could not be exploited for physics studies but has been successfully used for calibration aspects only.

There exists already some experience with polarized e^- beams at a linear collider, namely the e^+e^- Linear Collider SLC at SLAC. Since the beam polarization can not be generated via the Sokolov-Ternov effect at a linear collider one has to produce the polarization at the source and maintain it up to the interaction point without any significant depolarization. As already demonstrated in the past one applies also in the current LC designs the well-known strained photo-cathode technologies (see also the proceedings articles of PESP2010, Bonn, 2010), and expects an high e^- polarization of about 80%–90%.

At the SLC, one achieved a high electron polarization of about $P(e^-)$ 78% at the Z-pole which results in the best single measurement of the electroweak mixing angle $\sin^2 \theta_W = 0.23098 \pm 0.00026$, although the luminosity was about one order of magnitude less than the corresponding LEP data. This example already demonstrates the importance of polarized beams for specific observables.

Contrary to polarization of electrons, the polarization of e^+ beams at a linear collider is a technical novelty. There exist about three different methods how to generate polarized positrons: via undulator radiation, via Compton-backscattering and via bremsstrahlung of a polarized e^- beam. However, the luminosity requirements, see Table 1, put strong demands on the positron source and by now only the undulator source can actually be regarded as being feasible as polarized source for a future Linear Collider. It is expected to achieve a polarization $P(e^+) \leq 30\%$ already in the baseline design upgradable to about $P(e^+) \sim 60\%$. Further

details on the technical status of polarized e^+ sources at the ILC, see the following contributions [3, 4, 5, 6].

In order to fully exploit the polarization of the beams, one also has to measure precisely the actual degree of polarization. Therefore high precision polarimetry is mandatory. At the SLC one achieved already a precision of $\Delta P(e^-)/P(e^-) \sim 0.5\%$ with Compton polarimetry measured via a magnetic spectrometer. The goals at the ILC are even more challenging and one aims for $\Delta P(e^\pm)/P(e^\pm) \leq 0.25\%$. In order to achieve such a precision, Compton polarimeters in combination with a dedicated chicane system and Cerenkov detectors are implemented as upstream polarimeter. A downstream polarimeter is further required and is applicable due to the crossing angle. Further details, see [7]. Such a dual measurement enables machine feedback and provides access to a precise determination of the luminosity-weighted polarization at the interaction point if precise spin tracking is provided, see [8].

The main depolarization effects at a LC are the following two effects: the classical spin precession that is described via the Thomas–Bargmann-Michel-Telegdi equation (T-BMT) and the quantum-mechanical spin-flip process (Sokolov-Ternov effect). The largest effects are predicted for the beam-beam interaction region due to the strong field of the oncoming beam. Due such a strong field environment, higher-order quantum effects have to be calculated and taken into account as well, further details see [9]. The resulting depolarization effects have been evaluated and compared for the ILC RDR and the current CLIC design, see Table 2. Smaller depolarization effects are expected to occur in the damping rings, the spin rotators and the beam delivery system, but they have to be included. This work is still ongoing. For details on spin treatment in general, see [10].

Before a few examples for the impact of polarization in electroweak physics are highlighted, some fundamentals for physics with polarized beams are listed. The impact of polarized beams on supersymmetric models and further extensions of the Standard Model are discussed in [1], Part II of this article. A comprehensive overview of the physics case for the use of polarized electron and positron beams at a LC as well as a technical status report of the available polarized e^\pm sources at a LC is given in [11].

4. Basic observables with polarized beams

In the case of e^+e^- annihilation into a vector particle (in the SM this would be $e^+e^- \rightarrow \gamma/Z^0$) only the two $J = 1$ helicity configurations of the e^- and e^+ contribute, σ_{RL} and σ_{LR} . The cross section for arbitrary beam polarizations can then be expressed in a particularly compact way via the left-right asymmetry and the effective polarization that contains the complete dependence on beam polarization:

$$\begin{aligned} \sigma_{P_{e^-}P_{e^+}} &= \frac{1+P_{e^-}}{2} \frac{1-P_{e^+}}{2} \sigma_{\text{RL}} + \frac{1-P_{e^-}}{2} \frac{1+P_{e^+}}{2} \sigma_{\text{LR}} \\ &= (1-P_{e^-}P_{e^+}) \frac{\sigma_{\text{RL}} + \sigma_{\text{LR}}}{4} \left[1 - \frac{P_{e^-} - P_{e^+}}{1-P_{e^+}P_{e^-}} \frac{\sigma_{\text{LR}} - \sigma_{\text{RL}}}{\sigma_{\text{LR}} + \sigma_{\text{RL}}} \right] \\ &= (1-P_{e^+}P_{e^-}) \sigma_0 [1 - P_{\text{eff}} A_{\text{LR}}], \end{aligned} \tag{1}$$

with

$$\text{the unpolarized cross section:} \quad \sigma_0 = \frac{\sigma_{\text{RL}} + \sigma_{\text{LR}}}{4} \tag{2}$$

$$\text{the left-right asymmetry:} \quad A_{\text{LR}} = \frac{\sigma_{\text{LR}} - \sigma_{\text{RL}}}{\sigma_{\text{LR}} + \sigma_{\text{RL}}} \tag{3}$$

$$\text{and the effective polarization:} \quad P_{\text{eff}} = \frac{P_{e^-} - P_{e^+}}{1 - P_{e^+}P_{e^-}} \tag{4}$$

The values of the effective polarization can be read off from Fig. 1, a polarization of $P(e^-) = 90\%$ and $P(e^+) = 60\%$ ($P(e^+) = 30\%$), for instance, leads to $P_{\text{eff}} = 97\%$ ($P_{\text{eff}} = 94\%$). Notice that

the effective polarization is closer to 100% than either of the two beam polarizations in these cases.

Since the left-right asymmetry A_{LR} significantly depends on the polarization, its experimental uncertainty is determined by the polarization accuracy. Therefore this quantity benefits greatly from the use of simultaneously polarized e^- and e^+ beams: using eq.1, one can easily derive

$$\begin{aligned}\sigma_0 &= \frac{\sigma_{-+} + \sigma_{+-}}{2(1 + |P_{e^+}| |P_{e^-}|)} \\ A_{LR} &= \frac{1}{P_{\text{eff}}} A_{LR}^{\text{obs}} = \frac{1}{P_{\text{eff}}} \frac{\sigma_{-+} - \sigma_{+-}}{\sigma_{-+} + \sigma_{+-}},\end{aligned}\quad (5)$$

where A_{LR}^{obs} is the measured left-right asymmetry of processes with partially polarized beams.

The contribution of the uncertainty of the polarization measurement to the error in A_{LR} is given under the assumption that the errors are completely independent and added in quadrature:

$$\frac{\Delta P_{\text{eff}}}{P_{\text{eff}}} = \frac{x}{(|P_{e^+}| + |P_{e^-}|)(1 + |P_{e^+}| |P_{e^-}|)} \sqrt{(1 - |P_{e^-}|^2)^2 P_{e^+}^2 + (1 - |P_{e^+}|^2)^2 P_{e^-}^2} \quad (6)$$

$$\left| \frac{\Delta A_{LR}}{A_{LR}} \right| = \left| \frac{\Delta P_{\text{eff}}}{P_{\text{eff}}} \right|. \quad (7)$$

Equal relative precision $x \equiv \Delta P_{e^-}/P_{e^-} = \Delta P_{e^+}/P_{e^+}$ of the two beam polarizations is assumed.

It is immediately obvious from eq. (6), that $\Delta P_{\text{eff}}/P_{\text{eff}} < \Delta P_{e^-}/P_{e^-}$. The impact of positron polarization for the polarization contribution to the uncertainty of A_{LR} is shown in fig. 2. The improvement due to positron beam polarization is substantial. For a positron polarization of $P(e^+) = 60\%$ the error on A_{LR} is reduced by a factor of about 3, for $P(e^+) = 30\%$ by a factor of about 2.

Note: there is no gain in accuracy if only polarized electrons are available, even not in the case that one had $p(e^-) = 100\%$.

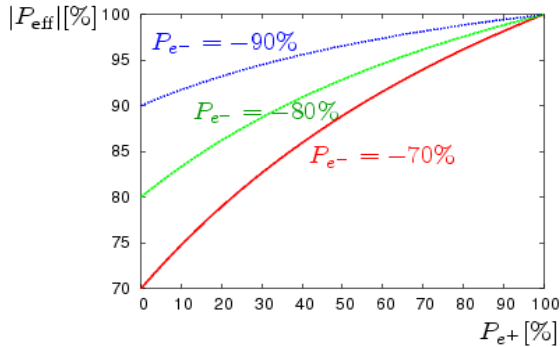


Figure 1. Effective polarization P_{eff} , eq. (4), versus positron beam polarization, P_{e^+} and for different P_{e^-} .

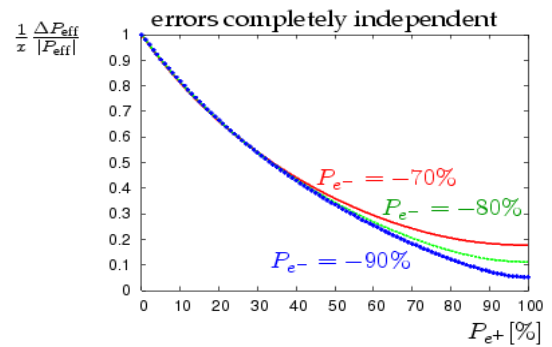


Figure 2. The relative uncertainty of $\Delta P_{\text{eff}}/|P_{\text{eff}}| \sim \Delta A_{LR}/A_{LR}$, eq. (7), where $x = \Delta P_{e^-}/P_{e^-} = \Delta P_{e^+}/P_{e^+}$.

5. Impact on electroweak precision measurements

Running with high luminosity at the Z-pole either with the GigaZ option at the ILC or with a dedicated Z-factory, provides measurements of electroweak precision observables as,

for instance, $\sin^2 \theta_{\text{eff}}$, m_Z , m_W , Γ_Z , etc. with unprecedented accuracy. The mixing angle $\sin^2 \theta_{\text{eff}} = 1 - \frac{m_W^2}{m_Z^2} + \text{loop effects at the Z-pole}$ is accessible via measurements of the asymmetry:

$$A_{\text{LR}} = \frac{2(1 - 4 \sin^2 \theta_{\text{eff}})}{1 + (1 - 4 \sin^2 \theta_{\text{eff}})^2}. \quad (8)$$

As discussed in the previous section, such a left-right asymmetry A_{LR} is particularly sensitive to effects from beam polarization and its accuracy can be easily enhanced by a factor 3 just by providing both beams simultaneously polarized. Measuring A_{LR} at the Z-pole with high precision is particularly important: there exists a large discrepancy between the derived value for $\sin^2 \theta_{\text{eff}}$ from A_{LR} measurement at SLC and that one from the A_{FB} measurement at LEP:

$$\sin^2 \theta_{\text{eff}} = 0.23098 \pm 0.00026 \quad \text{SLC}, \quad (9)$$

$$\sin^2 \theta_{\text{eff}} = 0.23221 \pm 0.00029 \quad \text{LEP} \quad (10)$$

As world average one uses

$$\sin^2 \theta_{\text{eff}} = 0.2315 \pm 0.00016. \quad (11)$$

The precise value of the world average has a great physics impact, for instance on the Higgs searches, as can be seen from the well-known plot Fig.3. The resolution of the discrepancy between the two most precise measurements is therefore particularly important. Since the theoretical prediction of $\sin^2 \theta_{\text{eff}}$ is sensitive to loop effects, a precise measurement of this quantity would provide valuable hints on the underlying physics model. However, the world average does not show a clear model preference neither for the SM nor for SUSY, see Fig. 4. The determination

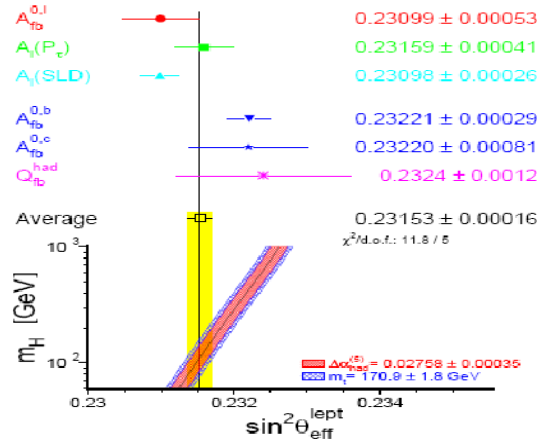


Figure 3. Individual measurements and world-average of $\sin^2 \theta_{\text{eff}}$. The exp. results are compared with the prediction within the SM as a function of the Higgs boson in the Standard Model for $m_t = 170.9 \pm 1.8 \text{ GeV}$ and $\Delta\alpha_{\text{had}}^{(5)} = 0.02758 \pm 0.00035$ [12].

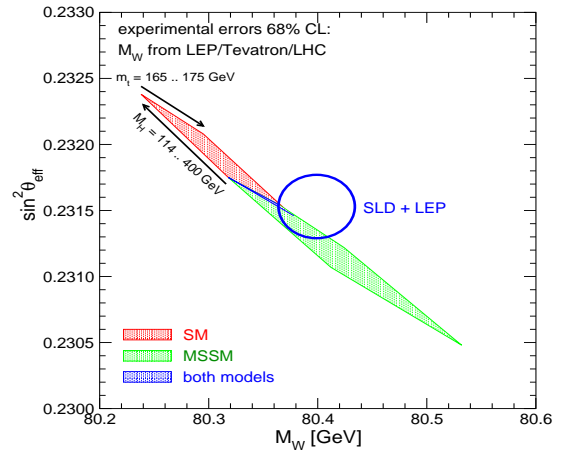


Figure 4. Precision on $\sin^2 \theta_{\text{eff}}$ from the measurement of A_{LR} (current world average LEP2/SLD); it is also shown the allowed parameter space of the SM and the MSSM in the $\sin^2 \theta_{\text{eff}} - m_W$ [13].

of the central value of $\sin^2 \theta_{\text{eff}}$ as well as its accuracy is of particular importance. For instance, a precise central value at the SLD value points to an underlying new physics scenario, the MSSM, see Fig. 5. Contrary, a central value at the measured LEP value is inconsistent by about a $2-\sigma$ effect with $\sin^2 \theta_{\text{eff}}$ in the SM as well as in the MSSM, see Fig. 6. An improvement in the accuracy

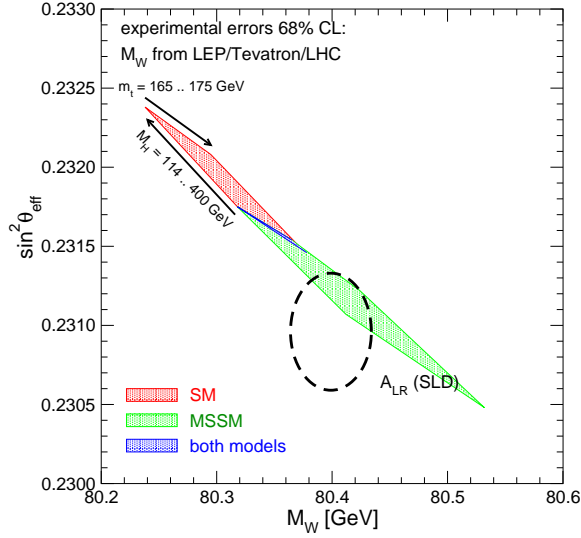


Figure 5. Precision on $\sin^2 \theta_{\text{eff}}$ from the measurement of A_{LR} at SLD. This value shows a clear preference for the MSSM [13].

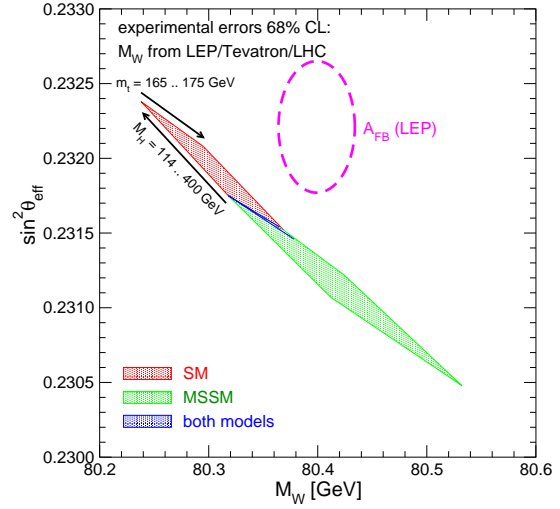


Figure 6. Precision on $\sin^2 \theta_{\text{eff}}$ from the measurement of A_{FB} at LEP. This value alone is neither consistent with the SM nor with the MSSM [13].

of about a factor 5, i.e. a hypothetical precision that is expected to be achievable at a Z -factory, would pin down the situation, see Fig.7. However, the uncertainty in the theoretical prediction of $\sin^2 \theta_{\text{eff}}$ suffers from parametric uncertainties of the dominant input parameters, m_t , $\Delta\alpha_{\text{had}}$ [14]: if $\Delta m_t = 1$ GeV (LHC expectations) $\rightarrow \Delta \sin^2 \theta_{\text{eff}}^{\text{para}} = 3 \times 10^{-5}$, but if $\Delta m_t = 0.1$ GeV (ILC expectations) $\rightarrow \Delta \sin^2 \theta_{\text{eff}}^{\text{para}} = 0.3 \times 10^{-5}$. On the other hand, $\Delta\alpha_{\text{had}} \sim 35 \times 10^{-5}$ causes $\Delta \sin^2 \theta_{\text{eff}}^{\text{para}} = 12 \times 10^{-5}$; since low energy experiments in the near future as well as the use of improved observables are planned, a significant reduction of the corresponding uncertainty is expected: $\Delta\alpha_{\text{had}} \sim 5 \times 10^{-5} \rightarrow \Delta \sin^2 \theta_{\text{eff}}^{\text{para}} = 1.7 \times 10^{-5}$. Currently, it is therefore reasonable to aim for a precision $\Delta \sin^2 \theta_{\text{eff}}$ at a Z -factory of about 3×10^{-5} . A nice example for the immediate need for a higher precision in $\Delta \sin^2 \theta_{\text{eff}}$ is the current CDF excess in $gg, p\bar{p} \rightarrow b\bar{b}b\bar{b}$. The current excess would be consistent with a specific MSSM scenario for $\tan\beta = 60$, the m_{max}^h scenario. The current world average in $\sin^2 \theta_{\text{eff}}$, however, is not precise enough to clarify the situation, cf. Fig. 9. Contrary, the m_{max}^h scenario at $\tan\beta = 60$ would be consistent with measured value at SLD, cf. Fig. 10.

6. Conclusions

Spin and polarization effects play a major role in determining and resolving the structure of the underlying physics model. In this first part an overview about technical design issues at a future LC with polarized beams and some fundamental relations between polarized observables have been summarized. In particular the impact of using simultaneously polarized e^\pm beams for electroweak high precision physics at the Z -pole has been discussed. The resolution of the discrepancy between $\sin^2 \theta_{\text{eff}}$ from A_{LR} and A_{FB} would have immediate physics impact on Higgs and beyond Standard Model physics.

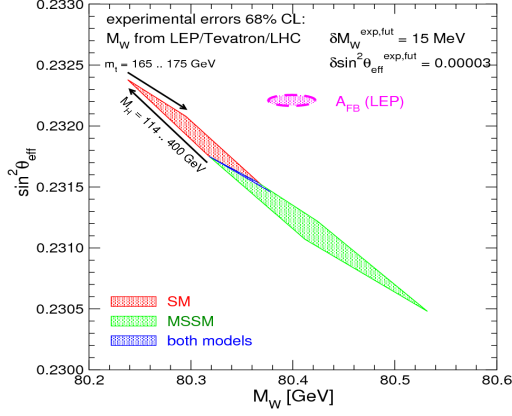


Figure 7. Under the hypothetical assumption that the central value measured at LEP is correct, the precision on $\sin^2 \theta_{\text{eff}}$ from the a possible measurement of A_{FB} with an accuracy expected at a Z-factory. With such a precision a clear clarification of the discrepancy might be possible. [13]

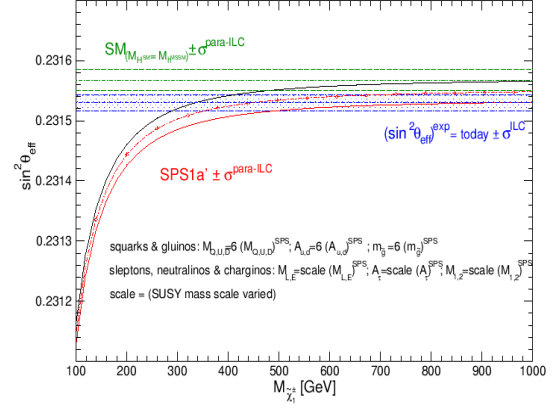


Figure 8. Theoretical prediction for $\sin^2 \theta_{\text{eff}}$ in the SM and the MSSM (including parametric theoretical uncertainties) compared to the exp. precision at the ILC with GigaZ. An SPS1a' scenario is used, where squark and gluino masses are fixed to 6 times their SPS1a' values. The other mass parameters are varied with a common scale factor. [15]

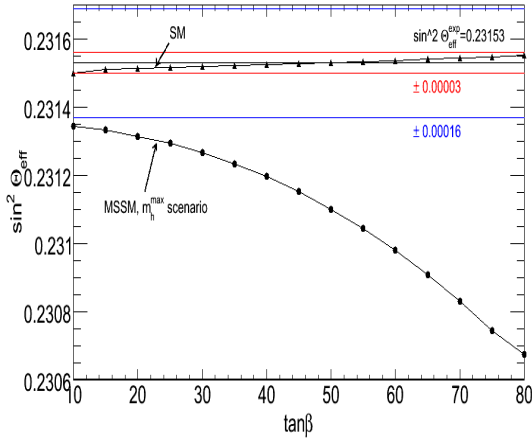


Figure 9. Current CDF excess in SUSY Higgs searches would be consistent with a specific MSSM scenario, ' m_h^{max} ', for $\tan \beta = 60$. World average of $\sin^2 \theta_{\text{eff}}$ would only be consistent with a SM-like Higgs [16].

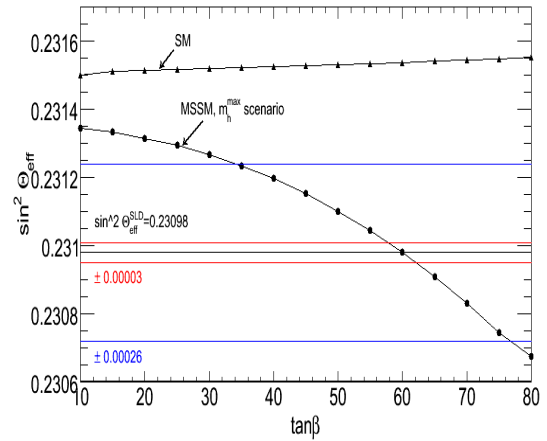


Figure 10. Central value of $\sin^2 \theta_{\text{eff}}$ measured at SLD would be perfectly consistent with the current CDF excess for a SUSY Higgs in the ' m_h^{max} ' scenario, but Z-factory precision required, to really nail facts down [16].

Table 1. Luminosity challenges for the e^+ source at ILC and CLIC in comparison with the SLC experience.

	SLC	ILC(RDR)	CLIC
e+/bunches	3.5×10^{10}	2×10^{10}	0.64×10^{10}
bunches/pulse	1	2685	312
Pulserepetition rate	120	5	50
e+/second	0.042×10^{14}	2.6×10^{14}	1×10^{14}

Table 2. Depolarization effects in the beam-beam interaction region for ILC with fully polarized beams (100/100), with partially polarized beams (80/30) and for the CLIC-G design [17].

Effect	Depolarization ΔP_{lw}		
	ILC 100/100	ILC 80/30	CLIC-G
Design			
T-BMT (spin precession)	0.17%	0.14%	0.10%
ST (spin flip process)	0.05%	0.03%	3.4%
incoherent pairs	0.0%	0.0%	0.06%
coherent pairs	0.0%	0.0%	1.3%
total	0.22%	0.17%	4.8%

Acknowledgments

The author would like to thank the organisers of the SPIN2010 conference for the welcoming and inspiring atmosphere. The author would also like to thank S. Heinemeyer, G. Weiglein, L. Zeune for private discussions and the preparation of plots specifically for this talk.

References

- [1] G. Moortgat-Pick, *Proc. of ‘Workshop on sources of polarized leptons and high brightness electron beams’ (PESP2010), September 2010, Bonn, Germany.*
- [2] P. Grannis, R. Heuer, S. Komamiya, M. Oreglia, F. Richard, D. Son, ILCSC Parameter Subcommittee, Parameters for the Linear Collider, Nov. 2006 and Sep. 2003.
- [3] S. Riemann, *Proc. of ‘Workshop on sources of polarized leptons and high brightness electron beams’ (PESP2010), September 2010, Bonn, Germany.*
- [4] A. Ushakov, *Proc. of ‘Workshop on sources of polarized leptons and high brightness electron beams’ (PESP2010), September 2010, Bonn, Germany.*
- [5] A. Schaelicke, *Proc. of ‘SPIN2010 – 19th International Spin Physics Symposium’, October, 2010, Jülich, Germany.*
- [6] K. Laihem, *Proc. of ‘SPIN2010 – 19th International Spin Physics Symposium’, October, 2010, Jülich, Germany.*
- [7] D. Käfer, *Proc. of ‘SPIN2010 – 19th International Spin Physics Symposium’, October, 2010, Jülich, Germany.*
- [8] M. Beckmann, *Proc. of ‘SPIN2010 – 19th International Spin Physics Symposium’, October, 2010, Jülich, Germany.*
- [9] A. Hartin, *Proc. of ‘SPIN2010 – 19th International Spin Physics Symposium’, October, 2010, Jülich, Germany.*
- [10] D. Baber, *Proc. of ‘SPIN2010 – 19th International Spin Physics Symposium’, October, 2010, Jülich, Germany.*
- [11] G. Moortgat-Pick et al., *Phys. Rep.* **460** (2008), 131 (Preprint hep-ph/0507011).
- [12] M. W. Grünewald, *J. Phys. Conf. Ser.* **110** (2008) 042008 (Preprint hep-ph/0709.3744); M. W. Grünewald, Preprint hep-ex/0710.2838.
- [13] S. Heinemeyer, G. Weiglein, private communication.
- [14] S. Heinemeyer and G. Weiglein, *Proc. of ‘2010 Linear Collider Workshop (LCWS10) and the International Linear Collider meeting 2010’, March, 2010, Beijing, China (Preprint hep-ph/1007.5232).*

- [15] S. Heinemeyer, W. Hollik, A. Weber, G. Weiglein, *JHEP***0804** (2008) 039, (Preprint hep-ph/0710.2972).
- [16] G. Weiglein, L. Zeune, in preparation.
- [17] I.R. Bailey, A.F. Hartin, G. A. Moortgat-Pick *et al.*, *Proc. of 11th European Particle Accelerator Conference (EPAC 08)*, June 2008, Magazzini del Cotone, Genoa, Italy.