Polarimetry at the ILC

Wolfgang Lorenzon

Randall Laboratory of Physics, University of Michigan, Ann Arbor, Michigan 48109-1040, USA

Impressions and thoughts about polarimetry at the ILC are presented. The Workshop on Beam Energy and Polarisation Measurement at the ILC was hosted at Desy Zeuthen from 9-11 April 2008. One of the goals was to explore beam polarimetry issues at the ILC to achieve 0.25% precision in polarization determination. No attempt is made to summarize the presentations or discussions. Instead, a personal reaction to these presentations and discussions is presented.

1 Introduction

In order to reach the physics goals and to fully exploit the discovery potential of the ILC, strong requirements are placed on precision polarimetry both for electrons and positrons. The current design of the ILC project foresees collisions of 45.6-500 GeV longitudinally polarized electrons and positrons. It is anticipated that the electron (positron) beam polarization is 80% (50%) or better and that it needs to be measured with unprecedented precision ($\lesssim$0.25% systematic uncertainty). This is a factor of two better than ever achieved before, and thus warrants special considerations. Before entering this new territory, it is advantageous to take a step back and consider what has previously been done in the field.

Table 1: Overview of existing polarimeters and their precision

Laboratory	**Polarimeter**	**Relat. precision**	**Dominant syst. uncertainty**
JLab	5 MeV Mott	~1%	Sherman function
	Hall A Møller	~2-3%	target polarization
	Hall B Møller	1.6% (→ 2-3%)*	target polarization, Levchuk effect
	Hall C Møller	0.5% (→ 1.3%)†	target polarization, Levchuk effect, high current extrapolation
	Hall A Compton	1% (@ >3 GeV)	detector acceptance + response
HERA	LPol Compton	1.6%	analyzing power
	TPol Compton	3.1%	focus correction + analyzing power
	Cavity LPol Compton	?	still unknown
MIT-Bates	Mott	~3%	Sherman function + detector resp.
	Transmission	>4%	analyzing power
	Compton	4%	analyzing power
SLAC	Compton	0.5%	analyzing power

* 1.6% is quoted by Hall B. 2% or even larger might be more realistic.

† 1.3% is best quoted value in an experiment. 0.5%, as quoted by Hall C polarimeter group, seems possible.

There are many polarimeters that have been in use, are in use, or are planned at various laboratories. Table 1 shows an overview of existing polarimeters and their precision in electron polarimetry[2]. The systematic uncertainties in beam polarization measurements for Compton polarimeters are reported to be in the 0.5-2% range, but they can get larger as measurements get pushed to lower beam energies ($E_b \lesssim 1.0$ GeV). For Møller scattering the systematic uncertainties are typically 2-3%, and may approach 1% or below at high magnetic fields.

Although the precision of the JLab polarimeters do not reach the precision required by the ILC, they still serve a valuable lesson in understanding the ultimate precision reachable in polarization measurements. The systematic uncertainties of the various polarimeters in the three experimental halls at JLab were each evaluated individually. Since it was possible to compare the polarization of the five polarimters with a special arrangement of the CEBAF accelerator, the "Spin Dance" Experiment was performed in July 2000 [3]. In this experiment, a multi-hall cross-normalization of the relative analyzing power of the five JLab electron polarimeters, listed in Table 1, was performed. The purpose of this comparison between the Mott, Compton, and Møller polarimeters was to reveal possible differences between the polarimeters that are systematic in nature and have not previously been accounted for. The results are displayed in Fig. 1 with the open symbols. There is significant discrepancy between the polarimeters, even if the systematic uncertainties are included.

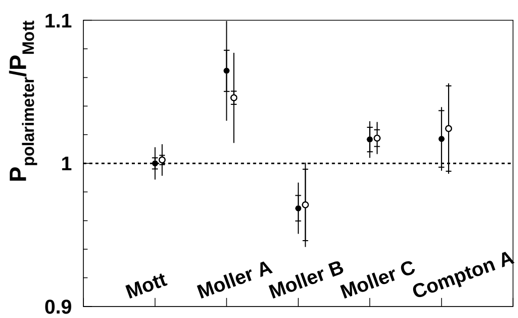

Figure 1: Relative analyzing power for the five JLab electron beam polarimeters, normalized to the Mott polarimeter for comparison. The open symbols are the results for the entire data set. The solid symbols represent the results for the data set limited to be within 25% of the maximum measured polarization.

Since the Hall A and B Møller polarimeters may have systematic effects that depend on the transverse components of the electron beam polarization, which are large when the longitudinal components are small, the data shown in solid symbols have been restricted to be within 25% of the maximum polarization value. These results indicate that the horizontal component of polarization may be an important source of systematic effects for the Hall A Møller polarimeter. For the reduced data set, the discrepancy among the five polarimeters becomes less significant. As a result of the spin dance experiment, the Hall A Møller polarimeter will be implementing a Hall C style target to be able to isolate instrumental from target polarization effects.

1.1 Lessons learned

Many lessons have been learned from these earlier polarization measurements. Experience at many laboratories has taught us that it is imperative to include polarization diagnostics and monitoring capabilities in the design of the beam lattice. It is important to ensure that the beam polarization can be measured continuously during data taking to minimize systematic uncertainties associated with the beam polarization, such as drifts or luminosity related variations in polarization. If at all possible, the beam polarization should be measured at the IP, or as close to the IP as possible. The laser and beam polarizations have to be flipped at intervals that are short compared to any drifts in polarization. The cross-comparison of the analyzing power of various polarimeters at JLab has shown that providing or even proving precision at the 1% level is challenging. Since the requirements at the ILC are even stricter, it is absolutely crucial that multiple devices are employed for testing the systematic uncertainties of each polarimeter. There has to be at least one technique that can measure the absolute polarization of the beam, while others can do relative measurements. Further, Compton scattering is the ideal process for measuring the polarization of high energy, high beam current electron (positron) beams. Compton scattering is a pure QED process where no atomic or nuclear corrections have to be applied, and where radiative correction uncertainties are at the 0.1% level [4].

To achieve sub-0.5% precision in the electron (positron) beam polarization determination, all these consideration have to be taken into account, and if possible, new and innovative ideas have to be employed.

2 Polarimetry at the ILC

The current scheme proposes three ways to measure polarization at the ILC; an upstream Compton polarimeter, a downstream Compton polarimeter and the $e^+e^- \to W^+W^-$ process which is measured at the IP and which is very sensitive to electron and positron polarization (at the level of 0.1%). There is however some significant complication in this scheme. The polarization at the IP is the luminosity-weighted polarization which is not identical to the beam polarization at the upstream polarimeter. Furthermore, although the downstream polarimeter measures the the luminosity-weighted polarization, there are depolarization and spin transport effects that are estimated to be at the 0.1-0.4% levels. Those effects are relatively large and of the same magnitude as the required accuracy, which makes it imperative that the uncertainties in these effects are well understood and can be kept small.

In order to make a convincing case for a 0.25% precision in electron and positron polarimetry, all three techniques are needed. It is suggested that the most accurate polarization values are determined for each polarimeter separately, while hiding the results from each other. It is then important to make sure that all depolarization and spin transport effects are understood. Only at this point the values for the up- and downstream polarimeters should be compared. If everything is understood properly, they should agree. This is, however, not the last step yet. The final calibration of the absolute polarization scale should be performed with the with $e^+e^- \to W^+W^-$ process. Only if all three measurements are in agreement, good confidence can be gained that the required precision has been achieved.

The up- and downstream polarimeters should be optimized separately, since each polarimeter is to be treated as a separate and independent (scattering) experiment. Each of them has different requirements and backgrounds. This means that there is no obvious reason to use the same type of laser for each polarimeter. Every effort should be taken to avoid any distraction from the goal of achieving a 0.25% measurement. This measurement is hard and should not be compromised by adding laser wire emmittance diagnostics or the MPS collimator to their apparatus. If possible, new ideas should be considered, if they can be implemented to improve the current scheme.

2.1 New Ideas for the ILC

New developments in laser technology might give a big boost to Compton scattering based polarization measurements, where it has been necessary to build either delicate laser cavity lasers or use high power pulsed lasers to get Compton rates that allow polarization measurements within reasonable time scales. This technology is being borrowed from fiber based drive lasers at electron sources that provide very high power, and use gain switching, as compared to mode locking which is sensitive to mode lock problems. The advantages are that they can be phase locked to the actual beam of the accelerator, therefore providing a nearly 100% duty cycle. In addition, fiber lasers can be easily accessed since they are external to the beam line vacuum system (unlike cavity lasers). They further provide excellent stability, low maintenance, and straightforward implementation. Efforts are underway to build a Compton polarimeter using the fiber lasers for a new Hall C Compton polarimeter.

There is general agreement that detection of Compton electrons is the best tool for high precision polarimetry. Since the analyzing power depends strongly on the momentum of the Compton electrons, Compton electrons are typically analyzed by fitting the asymmetry shape over parts or the entire available momentum range. Alternatively, the Compton edge (which corresponds to the minimum energy of the back-scattered Compton electrons), can be used to determine the electron beam polarization. These methods however depend strongly on the response function of the detector, which must be calibrated and monitored carefully. A new idea to do a zero-crossing Compton electron analysis is suggested. It relies on the well-defined energies of the zero crossing of the asymmetry (corresponding to $90°$ scattering in the electron rest frame) and of the Compton edge. This analysis is based on a linear fit of the zero crossing of the Compton asymmetry, and an integration of the asymmetry spectrum from that point to the Compton edge, instead of a fit to the spectrum shape between those points. It has the advantage that no absolute energy response calibration of the detector is necessary, and that the corrections due to finite detector position and energy resolutions are small ($\ll 1\%$).

3 Summary

In summary, it appears that electron (positron) beam polarimetry between 45.6-500 GeV seems possible at the 0.25% level. It presents a big challenge, but there are no apparent show stoppers. An impressive group of experienced physicists is involved in this endeavor with many good ideas and a lot of progress to show for. This group will want to build on their experience, and at the same time be open to new developments in the field. With much work already done, much is still ahead to optimize the design (i.e. analyzing power calibration, modeling of beam depolarization and spin transport, etc.).

References

[1] Slides:
`https://indico.desy.de/contributionDisplay.py?contribId=31&sessionId=8&confId=585`

[2] W. Lorenzon, "Precision Electron Beam Polarimetry", AIP Conference Proceedings No. 980, ed. A. Kponou, Y. Makdisi, A. Zelenski p. 407.

[3] J. M. Grames, et al., Phys. Rev. ST Accel. Beams, **4**, 042802 (2004).

[4] M.L. Swartz, et al., Phys. Rev. **D58**, 014010 (1998).