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Executive Summary of the Workshop on Polarisation and Beam Energy Measurements at the ILC

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This note summarizes the results of the "Workshop on Polarisation and Beam Energy Measurements at the ILC", held at DESY (Zeuthen) April 9-11 2008. The topics for the workshop included (i) physics requirements, (ii) polarised sources and low energy polarimetry, (iii) BDS polarimeters, (iv) BDS energy spectrometers, and (v) physics-based measurements of beam polarisation and beam energy from collider data. Discussions focused on the current ILC baseline programme as described in the Reference Design Report (RDR), which includes physics runs at beam energies between 100 and 250 GeV, as well as calibration runs on the Z-pole. Electron polarisation of $\mathcal{P}_{e^-} \gtrsim 80\,\%$ and positron polarisation of $\mathcal{P}_{e^+} \gtrsim 30\,\%$ are part of the baseline configuration of the machine. Energy and polarisation measurements for ILC options beyond the baseline, including Z-pole running and the 1 TeV energy upgrade, were also discussed.

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Seven recommendations requiring follow-up from the GDE and the Research Director have emerged from the workshop:

1. **Separate the functions of the upstream polarimeter chicane. Do not include an MPS energy collimator or laser-wire emittance diagnostics; use instead a separate setup for these two.**

2. **Modify the extraction line polarimeter chicane from a 4-magnet chicane to a 6-magnet chicane to allow the Compton electrons to be deflected further from the disrupted beam line.**

3. **Include precise polarisation and beam energy measurements for Z-pole calibration runs into the baseline configuration.**

4. **Keep the initial positron polarisation of 30-45% for physics (baseline).**

5. **Implement parallel spin rotator beamlines with a kicker system before the damping ring to provide rapid helicity flipping of the positron spin.**

6. **Move the pre-DR positron spin rotator system from 5 GeV to 400 MeV. This eliminates expensive superconducting magnets and reduces costs.**

7. **Move the pre-DR electron spin rotator system to the source area. This eliminates expensive superconducting magnets and reduces costs.**

1 Introduction

With the foreseen start of the Large Hadron Collider (LHC) in 2008, direct discoveries of new particles beyond the Standard Model (SM) are expected soon. According to the currently envisioned timeline for the International Linear Collider (ILC), first physics results could be available in 2020. Compared to the new energy frontier opened by the LHC, the ILC will open a new precision frontier, with beam polarisation playing a key role in a physics programme that demands precise polarisation and beam energy measurements [1].

In compliance with the RDR [2], the baseline configuration of the ILC already provides polarised electron and positron beams, with spin rotator systems to achieve longitudinal polarisation at the collider-IP; upstream and downstream polarimeters and energy spectrometers for both beams; and the capability to rapidly flip the electron helicity at the injector (using the source laser). Only the possibility of fast positron helicity flipping is not included in the baseline configuration.

The electrons will be highly polarised ($\mathcal{P}_{e^-} \gtrsim 80\,\%$), but also the positrons will be produced with an initial polarisation of about 30-45%. This expected small positron polarisation can either be destroyed or it can be used with great benefit for physics measurements if the possibility of fast helicity flipping of the positron spin is also provided. Excellent polarimetry accurate to $\Delta\mathcal{P}/\mathcal{P} = 0.25\%$ has been assumed in reference [3]. This number is technology-driven and can only be achieved with dedicated Compton polarimeters located upstream and downstream of the e^+e^- interaction region.

Precise beam energy measurements are necessary at the ILC in order to measure particle masses produced in high-rate processes. Measuring the top mass in a threshold scan to order 100 MeV or measuring a Standard Model Higgs mass in direct reconstruction to order 50 MeV [1] requires knowledge of the luminosity-weighted mean collision energy $\langle\sqrt{s}\rangle$ to a level of $1-2\cdot 10^{-4}$. Precise measurements of the incoming beam energy are a critical component to measuring the quantity $\langle\sqrt{s}\rangle$ as it sets the overall energy scale of the collision process.

Although precision polarisation and energy measurements at the Z-pole are not part of the current baseline as described in the RDR [2], we argue that the baseline should be modified to include such measurements. Z-pole calibration data would provide a unique possibility for an early calibration of the polarimeters and energy spectrometers in a well understood physics regime. Additionally, the calibration data can provide precision measurements of electroweak observables and thus serve as extremely sensitive tests of the SM, if the beam polarisation and energy are accurately measured. This is discussed in detail in a separate paper [4].

In any case, the actual polarisation state – as well as the energy of the beam – has to be known precisely to ensure the foreseen high precision physics measurements. The machine parameters needed for a linear collider to fulfill these physics requirements have been worked out [5]. It is mandatory that these requirements on polarisation, beam energy and luminosity measurements are technically achievable. Comparing the above quoted numbers with the typical precisions aimed for in the ILC physics program, it is clear that the goal for polarisation and energy measurements is limited by technology, whereas the physics programme would benefit from an even higher precision of both measurements.

2 Polarimetry

2.1 Sources, Low Energy Polarimetry and Spin Rotation

The electron source produces polarised electrons from a DC photocathode gun. The circular polarisation of the source laser beam is set with fast Pockels cells and the laser helicity can be reversed train-to-train, thereby allowing fast reversals of the electron spin. A Mott polarimeter located in a diagnostic line will be used to determine the electron polarisation near the source.

The positron source uses photoproduction to generate positrons [2]. The electron main linac beam passes through a long helical undulator to generate a multi-MeV photon beam, which then strikes a thin metal target to generate positrons in an electromagnetic shower. The positrons are captured, accelerated, separated from the shower constituents and unused photon beam and then are transported to the Damping Ring. Although the baseline design only requires unpolarised positrons, the positron beam produced by the baseline source has a polarisation of $\mathcal{P}_{e^+} \gtrsim 30\,\%$, and beamline space has been reserved for an eventual upgrade to 60% polarisation. No low energy polarimetry for the positron beam is foreseen in the RDR, but R&D work is ongoing. The positron polarisation could be measured near the source after the pre-accelerator using a Bhabha polarimeter at 400 MeV. After the damping ring, the positron polarisation could be checked with a Compton polarimeter. To save costs the laser of the laser wire system could be used, but design studies are not yet done. Since the RDR was written, simulation studies show that bunch (energy) compression would increase the positron capture effiency at the source, with which the positron polarisation could even reach $\mathcal{P}_{e^+} \gtrsim 45\,\%$ at the beginning of the ILC physics program. [6].

There are two ways to use the positron beam: (i) Physics measurements with a positron polarisation of about $\mathcal{P}_{e^+} \gtrsim 30-45\,\%$. (ii) Unpolarised positrons at the e^+e^-–IP. In the first case (i), the polarised positron beam is transported to the e^+e^-–IP with minimal spin diffusion and the degree of polarisation is measured with high precision of 0.25% near the interaction region with upstream and downstream polarimeters. Appropriate spin rotator systems are described in the RDR and are included in the beam transport lines from the Linac to the Damping Ring (LTR) and from the Damping Ring to the Linac (RTL) for both electrons and positrons. The left-right asymmetric structure of Standard Model processes requires a particular configuration of the initial state helicities, which should be randomly available to minimize systematic effects. So the effective luminosity can be increased, e.g. by a factor of 1.24 compared to $\mathcal{P}_{e^-} \gtrsim 80\,\%$ and zero positron polarisation, and the uncertainty of the effective polarisation given by $\mathcal{P}_{\rm eff} = \frac{|\mathcal{P}_{e^-}|+|\mathcal{P}_{e^+}|}{1+|\mathcal{P}_{e^-}|\,|\mathcal{P}_{e^+}|}$ can be reduced. The actual frequency of the helicity flip depends on the long time stability and reproducibility of machine parameters as luminosity, polarisation and background conditions. A helicity reversal for positrons less frequent than for electrons will cancel the gain in effective luminosity and would also reduce the improvement for the polarisation uncertainty. In the current baseline design, however, the positron helicity can only be slowly reversed by changing the polarity of the superconducting spin rotator magnets. This does not satisfy the demands of the precision physics program, which needs positron helicity reversals train-to-train as it is done for electrons.

Recommendation: Keep the initial positron polarisation of 30-45% (baseline). Modify the baseline configuration to provide random selection of the positron helicity train-by-train by implementing parallel spin rotator beamlines and kicker systems in the positron LTR [7].

Positron spin rotation and flipping could be done at 400 MeV rather than at 5 GeV [8], while the electron spin rotation could be done at the electron source using a Wien filter. The solenoid magnets necessary to rotate the spin from the transverse horizontal to the vertical direction can be smaller and less expensive, demanding less tunnel space at 400 MeV compared to 5 GeV. These modifications would eliminate expensive superconducting magnets, simplify the engineering for these systems, and reduce the costs.

Recommendation: Move the pre-damping-ring spin rotator systems to lower energy for both beams, electrons and positrons [8].

If, in the second case (ii), it should be decided to not deliver the 30-45% positron polarisation from the source to the experiment, a special scheme after the positron damping ring needs to be devised to completely destroy the positron polarisation in order not to adversely effect the physics measurements[a]. The zero positron polarisation also needs to be measured with high precision of 0.25%. Further studies are needed to ensure a left-over positron DC polarisation of about 0.1% will not affect physics measurements, which could result in the need for an even higher precision in this case.

In both cases it is required to measure the positron polarisation with high precision. We strongly recommend option (i) whereby physics measurements are possible with a positron polarisation of $\mathcal{P}_{e^+} \gtrsim 30\,\%$.

2.2 Overall Polarimetry Scheme

The ILC offers three methods to measure polarisation after acceleration: upstream and downstream of the IP, as well as using annihilation events. For the discussion on polarimetry

[a]Spin tracking studies [9] have shown that the horizontal projections of the spin vectors of an e^+ or e^- bunch do not fully decohere in the damping ring, even after 8000 turns.

it is important to distinguish the cases with and without positron polarisation. Without positron polarisation the cross section for all processes can be written as $\sigma = \sigma_0[1 - \mathcal{P}_{e^-} A_{\rm LR}]$. In this case the error on $A_{\rm LR}$ due to polarisation is $\Delta A_{\rm LR}/A_{\rm LR} = \Delta\mathcal{P}_{e^-}/\mathcal{P}_{e^-}$ but only the luminosity weighted averaged polarisation matters. If also positron polarisation is available the cross section can typically be written as $\sigma = \sigma_0\,[1 - \mathcal{P}_{e^+}\,\mathcal{P}_{e^-} + (\mathcal{P}_{e^+} - \mathcal{P}_{e^-})\,A_{\rm LR}]$. In this case the polarisations enter linearly and as a product so that the correlation between the two polarisations matters. The relevant quantity for physics analyses in this case is an effective polarisation, e.g. $\mathcal{P}_{\rm eff} = \frac{|\mathcal{P}_{e^-}|+|\mathcal{P}_{e^+}|}{1+|\mathcal{P}_{e^-}|\,|\mathcal{P}_{e^+}|}$, which due to favourable error propagation reduces the polarisation uncertainty by a factor of up to three.

Apart from the polarimeters, polarisation can also be measured using annihilation data [10], with direct access to the luminosity weighted polarisation. With electron and positron polarisation, four polarisation combinations are measurable for four unknowns so that the polarisation can be measured in a model independent way. With only electron polarisation this is not possible. However, W-pair production can be used to determine electron polarisation when only one beam is polarised with the only assumption that the $e\nu W$-coupling is purely left-handed which is well tested. The forward peak is entirely dominated by t-channel neutrino exchange and not influenced by possibly unknown triple gauge interactions. In both cases a 0.1% precision on the individual polarisations is possible, where, due to the favourable error correlation, the effective polarisation can even be measured to the 0.02% level. Nevertheless, annihilation methods can only provide polarisation measurements on very long time scales ($\gtrsim$ months) and need corrections from the polarimeters. Also, the model independent scheme with positron polarisation needs some statistics on all four helicity combinations, i.e. approximately about 30% of the running time [4, 11] has to be spent on the less interesting J=0 combinations. If the only reason to run at these states is polarimetry, polarisation measurements from annihilation data are fairly expensive.

The two polarimeters are highly complementary. The downstream polarimeter has access to the depolarisation in the interaction while the upstream polarimeter has a much higher counting rate and time granularity which is important for correlation measurements. Both properties are needed for a high precision analysis. Outside collisions the two polarimeters can calibrate each other.

To obtain a useful polarisation measurement the beam trajectories are required to be aligned to less than 50 μrad at the upstream Compton-IP, the collider-IP, and the downstream Compton-IP. This should be achievable by the beam delivery system (BDS) alignment as described in the RDR. However, the impact of the IR magnets and the crossing angle on the spin alignment needs to be addressed more thoroughly. In the extraction line, corrector magnets are needed to successfully compensate possible deflections resulting from misaligned beam and detector solenoid axes. The upstream polarimeter system, which is about 1800 m upstream of the e^+e^-–IP with a 1.5 m horizontal offset will require precision alignment methods. In addition, it should be possible to correlate polarimeter measurements with local BPM measurements, and the downstream polarimeter will want to correlate its measurements with the BPM measurements at the e^+e^-–IP [12]. This requires the BPM system to provide information to the polarimeter DAQ including bunch number identification. (Toroid information will also need to be provided to the DAQ.)

For the final polarisation measurement at the ILC it is therefore indispensable to have upstream and downstream polarimetry and get an absolute calibration from annihilation data. The polarimeters provide corrections and measure the polarisation on short scales like for individual scan points in an energy scan, while the annihilation data can check the absolute calibration on very long timescales. To keep the corrections small, every effort should be made to flip electron and positron polarisation frequently, if possible train by train. For the small errors envisaged at the ILC, a possible cross check of the different ways to measure polarisation is mandatory. This has also been confirmed by the polarimetry experience at SLC and by the beam-energy measurements at both, LEP and SLC.

2.3 The Upstream Polarimeter

The upstream polarimeter is located at the beginning of the BDS, upstream of the tuneup dump and at a distance of roughly 1.8 km to the e^+e^-–IP. In this position it benefits from clean beam conditions and very low backgrounds compared to any location downstream of the IP. It is therefore suited to provide very fast and precise measurements of the polarisation before collisions.

A complete conceptual layout for the upstream polarimeter had already been worked out for TESLA in 2001. However, for the ILC, a dedicated chicane-based spectrometer was adopted for upstream polarimetry in 2005, as this configuration allows the usage of a single laser wavelength at all beam energies when the spectrometer is operated with a fixed magnetic field. In this original design with a dedicated fixed-field chicane, the upstream polarimeter promised to be a superb and robust instrument with broad spectral coverage, very low background, excellent statistical performance for all machine bunches, and a high degree of redundancy. If equipped with a suitable laser, for example a similar one as used at the TTF/Flash source, which is now in operation at DESY, it can include every single bunch in the measurement. This will permit virtually instant recognition of variations within each bunch train as well as time dependent effects that vary train-by-train. The statistical precision of the polarisation measurement will be already 3% for any two bunches with opposite helicity, which leads to an average precision of 1% for each bunch position in the train after the passage of only 20 trains (4 seconds). The average over two entire trains with opposite helicity will have a statistical error of $\Delta\mathcal{P}/\mathcal{P} = 0.1\%$.

The statistical power of the upstream polarimeter depends almost exclusively on the employed laser and therefore to first order factorizes from other design aspects. However the crucial issue which drives the design of the whole polarimeter is to reach an unprecedented low systematic uncertainty of $\delta P/P \leq 0.25\%$ or better [13] with the largest uncertainties coming from the analyzing power calibration (0.2%) and the detector linearity (0.1%).

In an effort to reduce the cost of the long and expensive BDS system, the BDS management decided in autumn 2006 to combine other diagnostic and machine functions with the upstream polarimeter chicane. A machine protection system (MPS) energy collimator, defining the energy acceptance of the subsequent tune-up dump and a photon detector for laser-wire based emittance diagnostics were incorporated in the original upstream polarimeter chicane. The implications of these functional unification measures for polarimetry are rather severe and have since been the subject of protracted debate between the diagnostics groups and the BDS management. At this time, the conflicts have not yet been resolved. The following principal issues exist:

(i) *MPS energy collimator:* The collimator is planned to be 3 m long with a ±10% momentum aperture, although there is no concrete design available yet. Its insertion into the polarimeter magnetic chicane will completely obstruct the tapered vacuum chamber which had been designed to minimize wakefield effects.

(ii) *Collimator generated backgrounds:* Depending on the details of the structure, background generated from beam halo and jitter can grow to such a degree that it becomes very difficult (if not impossible) to provide a precise polarisation measurement.

(iii) *Fixed versus scaled field operation:* Fixed-field operation is the raison d'être of the entire chicane for polarimetry, but since the MPS insertion would demand complicated and costly movable jaw engineering in vacuum, the BDS management has asked for a scaled-field operation. While an adequate scaled-field operation, over limited energy ranges, would be possible for polarimetry, the operation would be much more complicated and the overall performance greatly reduced. Most importantly, it would effectively render all low-energy polarimetry impossible with no prospect of regaining this loss as long as the MPS object remains in this place.

(iv) *Incorporation of emittance diagnostics:* From the outset it was clear that a detector placed directly in the neutral beamline would not have adequate clearance from the charged beam path in the chicane at beam energies much higher than 250 GeV. A detector at this location would be bombarded with synchrotron radiation [14] and high-energy bremsstrahlung generated by beam gas interactions in the upstream beam line. In recognition of these problems, the laser-wire group is now exploring alternatives, including indirect photon detection from a converter target [15] and Compton electron detection. However, any material (e.g. converter) inserted into the neutral beam line, will naturally generate more background in the polarimeter hodoscope detector, thereby compromising the otherwise clean environment of the upstream polarimeter.

Compton electron detection seems to be a viable and promising alternative without introducing new backgrounds. It would require the insertion of retractable detectors in the chicane vacuum chamber, thus requiring some nontrivial engineering. For an adequate separation of the Compton recoil electrons from the original beam at low beam energies, this technique is only practical for fixed-field operation of the chicane. This is just one more good reason to dismiss the scaled-field scenario.

The description of the upstream polarimeter chicane combined with the MPS energy collimator and the laser-wire detection system given in the RDR is not satisfactory. The laser-wire detection system needs significant R&D to demonstrate a viable system, even in a standalone system separate from the polarimeter chicane.

In our judgement, it has been a very unreasonable decision to place the MPS energy collimator into the polarimeter chicane. Apart from a host of very serious engineering issues, the negative impact of scaled-field operation is severe, particularly at low beam energies. While physics data taking at the Z-pole is not part of the ILC baseline program, the capability for excellent polarimetry at the Z-pole should not be precluded. Consequently, an alternative placement for the MPS collimator should be created, preferably in conjunction with the laser-wire emittance diagnostics. If such an alternate place does not exist within the baseline BDS, it will also not exist in a post baseline upgrade of the BDS, thereby jeopardizing Z-pole polarimetry.

Recommendation: Separate the functions of the upstream polarimeter chicane. Do not include laser-wire emittance diagnostics or an MPS energy collimator; use instead a separate setup for these two.

2.4 The Downstream Polarimeter

The downstream polarimeter is located about 150 m downstream of the e^+e^-–IP in the extraction line and on axis with the IP and IR magnets. It can measure the beam polarisation both with and without collisions, thereby testing the calculated depolarisation correction which is expected to be at the 0.1-0.2% level.

A complete conceptual layout for the downstream polarimeter exists, including magnets, laser system and detector configuration. Three 10 Hz laser systems can achieve Compton collisions for three out of 2800 bunches in a train. Each laser will sample one particular bunch in a train for a time interval of a few seconds to a minute, then select a new bunch for the next time interval, and so on in a pre-determined pattern. The Compton statistics are high with about 300 Compton scattered electrons per bunch in a detector channel at the Compton edge.

With this design, a statistical uncertainty of less than 1% per minute can be achieved for each of the measured bunches. This is dominated by fluctuations in Compton luminosity due to beam jitter and laser targeting jitter and to possible background fluctuations. The statistical error due to Compton statistics in one minute, for a bunch sampled by one laser, is 0.3%. However, if compared to the average precision of the upstream polarimeter, a similar precision for each bunch position in a train could only be reached after about 17 hours.

Background studies have been carried out for disrupted beam losses and for the influence of synchrotron radiation. There are no significant beam losses for the nominal ILC parameter set and beam losses look acceptable even for the low power option. A synchrotron radiation collimator protects the Compton detector and no significant SR backgrounds are expected. The systematic precision is expected to be about 0.25%, with the largest uncertainties coming from the analyzing power calibration (0.2%) and detector linearity (0.1%).

The extraction line polarimeter chicane described in the RDR has four magnets with the same deflection in each magnet system. A proposal to modify the downstream polarimeter chicane to a six-magnet chicane was presented to the ILC in March 2007 [16]. The additional two magnets after the Compton detector allow the third and fourth magnets of the polarimeter chicane to be operated at higher field to deflect the Compton electrons further from the beam line and return the beam to the nominal trajectory.
Recommendation: Modify the extraction line polarimeter chicane from a 4-magnet chicane to a 6-magnet chicane to allow the Compton electrons to be deflected further from the disrupted beam line.

3 Beam Energy Measurements

The strategy which has been followed in the ILC design is to have redundant beam-based measurements of the incoming beam energy, capable of achieving a 10^{-4} relative precision on a single beam. This would be available in real time as a diagnostic tool to the operators and would provide the basis for the $\langle\sqrt{s}\rangle$ determination. Additional physics reference channels, such as $e^+e^- \to \mu^+\mu^-\gamma$ where the muons are resonant with the known Z-mass, are then foreseen to provide valuable cross-checks of the collision scale, but only long after the data has been recorded.

The two primary methods planned for making precise beam energy measurements are a non-invasive BPM-based spectrometer, located upstream of the interaction point just after the energy collimators, and a synchrotron imaging detector which must be located downstream of the IP in the extraction line to the beam dump. The BPM-based device is modeled after the spectrometer built for LEP-II which was used to calibrate the energy scale for the W-mass measurement, although the parameters of the ILC version are tightly constrained by allowances on emittance dilution in the beam delivery system. The synchrotron imaging detector is similar in design to the spectrometer used at SLAC for the SLC program. Both are designed to provide an absolute measurement of the beam energy scale to a relative accuracy of 10^{-4}. The downstream spectrometer, which observes the disrupted beam after collisions, can also measure the energy spectrum of the disrupted beam.

3.1 Upstream Energy Spectrometer

The canonical method to measure the beam energy E_b upstream of the e^+e^-–IP is the BPM-based spectrometer. A prototype test setup for such an instrument was proposed and commissioned in 2005, the T-474 experiment in the End Station A beamline at SLAC. The setup involves four dipole magnets and high-precision BPMs in front, behind and in between the magnets. ESA test beams operate at 10 Hz parasitically to PEP-II operation, with a bunch charge of $1.6 \cdot 10^{10}$ electrons, a bunch length of 500 μm and an energy spread of 0.15%, i.e. with properties similar to ILC expectations. The beam energy is directly deduced from the offset measurements of 5 mm, which is also designed for the present ILC baseline energy spectrometer. When combining all the BPM stations to measure the precision of the orbit over the whole ESA-chicane beamline, a resolution of 0.82 μm in x and 1.19 μm in y was achieved. The system turned out to be stable at the micron level over the course of one hour. The long term stability was affected by relative scale drifts across all the BPMs. In particular, drifts of ± 10 μm were observed over 18 hours of operation. However, the stability of new designed ILC prototype BPMs located in the mid-chicane were stable to $\pm$ 0.25 μm over a period of one hour and ± 1 μm over the period of 18 hours. Their stability was influenced by low amplitude effects and mechanical vibration on short time scales. First results of the T-474 experiment were published, see e.g. [17], and support the successful operation of the testbench. Analyzing the data from 2007 runs is ongoing and final results are expected within the next few months. The T-474 experiment is not continuing past 2007 because of the cessation of the ESA test beam programs at SLAC.

3.2 Extraction-Line Energy Spectrometer

At the SLC, the WISRD (Wire Imaging Synchrotron Radiation Detector) [18] was used to measure the distance between two synchrotron stripes created by vertical bend magnets which surrounded a precisely-measured dipole that provided a horizontal bend proportional to the beam energy. This device achieved a precision of $\delta E_b/E_b \sim 2 \times 10^{-4}$, where the limiting systematic errors were due to relative component alignment and magnetic field mapping. The ILC Extraction-Line Spectrometer (XLS) design is largely motivated by the WISRD experience.

The analyzing dipole for the XLS is provided by a vertical chicane just after the capture quad section of the extraction line, about 55 meters downstream of the interaction point. The chicane provides a ± 2 mrad vertical bend to the beam and in both legs of the chicane horizontal wiggler magnets are used to produce the synchrotron light needed to measure the beam trajectory. The optics in the extraction line are designed to produce a secondary focus about 150 meters downstream of the IP, which coincides with the center of the polarimeter chicane and the Compton interaction point. The synchrotron light produced by the wigglers will also come to a vertical focus at this point, and position-sensitive detectors in this plane arrayed outside the beampipe will measure the vertical separation between the synchrotron stripes.

With a total bend angle of 4 mrad, and a flight distance of nearly 100 meters, the synchrotron stripes will have a vertical separation of 400 mm, which must be measured to a precision of 40 μm to achieve the target accuracy of 10^{-4}. In addition to the transverse separation of the synchrotron stripes, the integrated bending field of the analyzing dipole also needs to be measured and monitored to a comparable precision of 10^{-4}. The distance from the analyzing chicane to the detectors needs to only be known to a modest accuracy of 1 cm.

In the original SLC WISRD, photoemission of electrons from thin wires on 100 μm pitch was used as the detection mechanism. This scheme suffered from several experimental issues, including cross-talk and RF pickup. For the XLS spectrometer, it has been proposed to use an array of radiation-hard 100 μm quartz fibers. These fibers do not detect the synchrotron light directly, but rather detect Cherenkov radiation from secondary electrons produced when the hard photons interact with material near the detector. At ILC beam energies, the critical energy for the synchrotron radiation produced in the XLS wigglers is several tens of MeV, well above the pair-production threshold, and copious numbers of relativistic electrons can be produced with a thin radiator in front of the fiber array. The leading candidate for reading out these fibers are multi-anode PMTs from Hamamatsu, similar in design to those used in scintillating fiber calorimeters. The advantage of this scheme over wires is to produce a reliable, passive, rad-hard detector which does not suffer from cross-talk or RF pickup, and still allows for easy gain adjustment and a large dynamic range.

The energy spectrum of beam after collision contains a long, tail as a result of the beam-beam disruption in the collision process. This disrupted beam spectrum is not a direct measure of the collision energy spectrum, but it is produced by the same physical process, and direct observation of this disrupted tail will serve as a useful diagnostic for the collision process. The position-sensitive detector in the XLS is designed to measure this beam energy spectrum down to 50% of the nominal beam energy. Near the peak, for a beam energy of $E_b = 250$ GeV, each 100 micron fiber spans an energy interval of 125 MeV. Given a typical beam energy width of 0.15%, this means the natural width of the beam energy will be distributed across at least a handful of fibers, which will allow the centroid to be determined with a precision better than the fiber pitch, and some information about the beam energy width can be extracted as well.

3.3 R&D on Alternative Methods

R&D on three alternative methods for precise beam energy measurements with 100 ppm accuracy is being carried out by different groups. The first method utilizes Compton backscattering, a magnetic spectrometer and precise position measurements of the electron beam, the centroid of the Compton photons and the kinematic edge of the Compton-scattered electrons [19, 20]. The spectrometer length needed is about 30 m and would be located near the upstream polarimeter. Precise position measurements approximately 25 meters downstream of an analysis magnet are needed with accuracies of 1 μm for the Compton photons, 10 μm for the Compton edge electrons and 0.5 μm for the beam electrons. Presently, a proposal to perform a proof-of-principle experiment at Novosibirsk is in preparation. Detailed studies are also in progress to understand whether a combination of the upstream polarisation chicane with a Compton energy spectrometer is possible.

The second method utilizes the synchrotron radiation (SR) emitted in the dipole magnets of the upstream BPM-based spectrometer [21]. Accurate determination of the edges of the SR fan is needed. Studies include a direct measurement of the SR fan as well as the use of mirrors to deflect soft SR-light to detectors located away from the beamline. Novel high-spatial resolution detectors are considered, and a gas amplification detector is now under study in Dubna with first results expected later this year.

A third method relies on the Resonance Absorption method [22, 23]. Under certain conditions, laser light can be absorbed by beam particles when both co-propagate in close proximity in a solenoid. The beam energy can be inferred from the measured dependence of light absorption on the magnetic field and laser wavelength. Studies are underway at Yerevan regarding theoretical uncertainties, and design of the laser system and laser light detectors.

4 Z-pole Calibration Data

Precise energy and polarisation measurements at the Z-pole are not required in the RDR or in the ILC baseline parameters document. But, both measurements are important and should be included in the ILC baseline for the following reasons:

- Polarimeter calibration and cross-check against physics based polarisation measurements using the Blondel scheme;
- Calibration of energy measurement against Z-pole mass (included in the RDR and in the ILC baseline parameters document)
- Data from these calibration runs can also provide significant statistics for physics measurements.

For a more detailed summary as to what can be done with the Z-pole calibration data the reader is referred to [4].
Recommendation: Include precise polarisation and energy measurements for Z-pole calibration runs in the baseline. This is needed for calibration cross checks of the polarimeters and energy spectrometers.

5 Upgrade to $\sqrt{s} = 1$ TeV

An energy upgrade to 1 TeV center-of-mass after the completion of the baseline programme should not be compromised in any way. Measures should be taken not to render polarimetry impossible at beam energies higher than 250 GeV. This includes building beam diagnostics, especially the polarimeter chicanes, in a way that permits an easy upgrade to operate at high beam energies.

In this context again the combination of emittance diagnostics, machine protection and polarimetry as proposed in the RDR is extremely problematic, if not unfeasable, and we strongly recommend to separate these functions. First of all, the “scaled field” or “fixed dispersion” operating scenario for the upstream chicane cannot be retained up to 500 GeV beam energy. This would lead to completely unacceptable synchrotron radiation losses and emittance blow-up. Secondly, if the dispersion would inevitably be scaled down to about 10 mm, the energy collimator will end up having a ± 1 mm aperture (2 mm opening for a length of 3 m). This would be very problematic to operate even under nominal machine conditions and generate totally unacceptable background conditions for polarimetry. Lastly, the performance of the laser-wire photon detector is already not really acceptable at lower beam energies, but at 500 GeV beam energy the proposed system will become unfeasible.

6 Conclusions and Recommendations

The "Workshop on Polarisation and Beam Energy Measurements at the ILC" was accompanied by W. Lorenzon (Univ. of Michigan) and K. Mönig (DESY-Zeuthen) as referees. In his conclusions, W. Lorenzon stated that it is already all but trivial to provide or even prove an analyzing power precision at the 1% level. He impressively showed this by discussing the setup and results of the "Spin Dance" experiment performed at JLab (Thomas Jefferson National Accelerator Facility) in July 2000 [24, 25]. In this experiment, a cross-normalisation of the relative analyzing power of the five electron polarimeters was performed to reveal possible systematic differences between the polarimeters that had not yet been accounted for. Although the systematic uncertainties of all polarimeters (1 Mott, 3 Møller, 1 Compton) were each evaluated individually, the experiment clearly showed significant discrepancies between the polarimeter results, even if the systematic uncertainties were included.

Furthermore, both referees argued that it is absolutely crucial to employ multiple devices for testing and controling the systematic uncertainties of each polarimeter [10, 24]. They also suggested to treat the upstream and downstream polarimeters as independent experiments and thus optimise them separately. This also implies that there is absolutely no need for both polarimeters to use the same type of laser, since the requirements and backgrounds also differ significantly. Their clear recommendations are to avoid any distraction from the ambitious goal of achieving a 0.25% measurement of the beam polarisation.

It was also strongly recommended to keep the initial positron polarisation of 30-45% to improve the gain in effective luminosity and enable physics measurements, which would not be possible without positron polarisation. In any case the positron beam will be polarised from the start due to the helical undulator source used to generate the positrons.

The motivation for having both, upstream and downstream diagnostics, includes complementarity, redundancy and intercalibration of the systems. As can easily be seen from the experiences at SLC and at LEP, independent measurements proved to be important for both, polarimetry and energy measurements. Also, over a decade of operational experience with multiple Compton polarimeters at HERA clearly demonstrated the necessity for such redundancy, both in terms of systematic cross checks and in terms of operational reliability.

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