SLD-Note-255
May 1997

The QFC polarimeter : Background Problem

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Abstract

This note presents the results of commissioning of the Quartz Fiber Calorimeter during the SLD '96 run. Very high level of background turned out to be the main problem for the detector, and a specific study was carried out to identify its source and to find a way to reduce it. Scattered synchrotron radiation from the Hard Bend Magnet was found to be the major cause of the QFC background. It was simulated in detail by GEANT, and good agreement between data and Monte-Carlo was achieved. Based on the results of the simulation, the detector was modified and a new shielding was designed and constructed. The note presents our proposal for the polarization measurement with the QFC polarimeter during the '97 run.

1 Introduction

Construction of a calorimetric device to detect backscattered Compton photons and provide an independent cross-check for the polarization measurement by the existing Compton Polarimeter [1] was proposed by C.Prescott [2] and M. Fero et al. [3] in 1993. Such device, based on quartz fiber technology [4], was designed and constructed by the University of Tennessee team [5]. The calorimeter was installed in the SLC South Final Focus in December 1995.

The Quartz Fiber Calorimeter (QFC) determines the longitudinal polarization of the electron beam by measuring the asymmetry in the Compton photons energy flow between parallel and anti-parallel combinations of the photon and electron beam helicities. It is also designed to determine the transverse polarization of the electron beam by measuring the angular asymmetry. For the SLD Compton polarimeter system, asymmetry in the energy flow is about 17 % for 100 % longitudinally polarized electron beam, and the displacement between centroids of the position distributions for Compton photons produced by electrons and photons in the two different helicity combinations is 25.4 μm for 100 % transverse polarization of the electron beam.

To operate in the SLC Final Focus environment, the detector should be compact, fast, extremely radiation hard and insensitive to high fluxes of low energy synchrotron radiation. A quartz fiber technology and tungsten absorber were chosen to satisfy these requirements.

The calorimeter is formed by a longitudinal stack of thirty four 3.5 mm thick tungsten plates which have precisely machined 14 mm wide grooves in alternatingly horizontal and vertical directions. Thirty eight 360 micron polyimide buffered quartz fibers fit tightly inside each groove. The tungsten plates are shaped such that the device can be positioned very close to the electron beam pipe. The calorimeter is mounted on a remotely operated micrometer stage allowing position adjustment in both vertical and horizontal directions.

Ĉerenkov light produced in the quartz fibers is read out by 24 PMTs placed in a lead shielded box. The box also contains an LED source used for calibration and monitoring of gain stability and potential radiation damage to the fibers. Three adjacent fibers in each coordinate fiber plane are grouped together (four fibers closest to the edge of the groove on each side of the calorimeter are not used in coordinate layers).

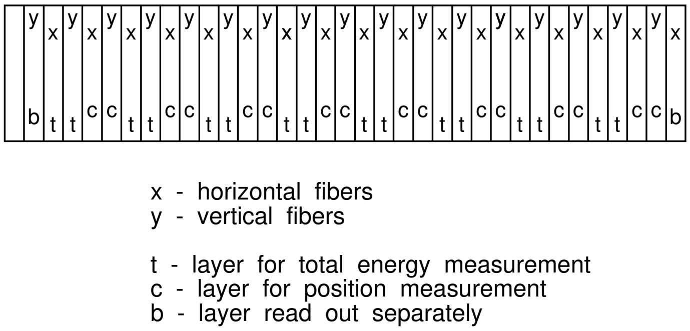

Fig. 1 The QFC calorimeter read-out scheme.

Fibers are also grouped longitudinally in vertical and horizontal layers, thus forming two independent calorimeters for position measurements in both directions. Coordinate layers with segmented readout are alternated with similar vertical and horizontal layers for total energy measurement, read out by two separate PMTs. Thus, one half of the fiber planes is used for coordinate measurements (total of 20 channels, 10 in each direction) and the other half for total energy measurements (2 “amplitude” channels, one for X-fibers and one for Y-fibers). The first and the last longitudinal layers have no transverse segmentation and are read out separately to provide additional information on the background seen by the detector (so called “Forward Background” and “Back Background” channels). The calorimeter read-out scheme is shown in figure 1.

To avoid the background from the beamstrahlung photons, the detector is operated during special time periods when there is no positron beam present. Preliminary studies have shown that the systematic uncertainty of the longitudinal polarization measurement with the QFC can be understood at the level of 0.4 %. Systematic error of the transverse polarization measurement is dominated by the beam position stability. In the absence of background, statistical error below 1 % could be achieved after a few minutes of measurements.

2 Performance during the SLD '96 run

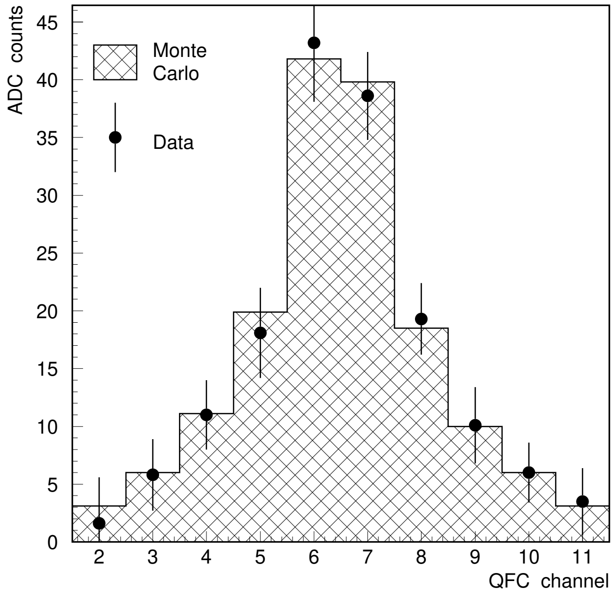

Fig. 2 Background-subtracted transverse profile of Compton signal in the quartz fiber calorimeter. Monte Carlo total energy is normalized using the data.

The QFC was commissioned during the '96 run. In terms of its intrinsic characteristics, the detector operated in a good agreement with its design specifications (figure 2 shows the transverse profile of the Compton signal in the QFC and its comparison with the Monte-Carlo), but the level of background turned out to be very high and did not allow to achieve the desired accuracy of the polarization measurement.

With the signal-to-background ratio of 1:25 to 1:50, the error in the longitudinal polarization measurement was about 7 % or higher for a 3 minute polarimeter run, and was completely dominated by the background fluctuations. Combining all the usable data taken with the QFC throughout the '96 run (about 2.5 hours worth of data, most of which was taken under less than perfect beam conditions), the average longitudinal polarization as measured by the QFC was calculated to be 73.03 $\pm$ 2.58 %. The polarization measured by the Ĉerenkov spectrometer for the same data sample was 69.31 $\pm$ 0.53 % (this is significantly lower than average for the run because most of the QFC data was taken in a background to various other studies requiring electron-only beam, like spin bumps optimization, with the beam setup off nominal).

3 Backgrounds

Special studies were carried out to identify the source of an extremely high background observed by the QFC and to find a way to reduce it.

After passing through the Compton interaction point, the electron beam is deflected by a pair of dipole magnets, generating a high flux of synchrotron radiation. The first of the two magnets, Soft Bend Magnet (SB), has a magnetic field of 0.385 kGauss and produces a deflection angle of 1.0 mrad, generating 462 TeV of synchrotron radiation per electron bunch (as compared to about 15 TeV energy carried by Compton-scattered photons) with a critical energy of 53.2 keV. This radiation, as well as synchrotron radiation generated by the core of the electron beam in upstream quadrupoles, is effectively suppressed by the Ĉerenkov threshold of the quartz fibers (198 keV for electrons). The second dipole magnet, Hard Bend Magnet (HB, or B1), has a field value of 11.69 kGauss and a bend angle of 17.3 mrad, producing $2.43 \cdot 10^5$ TeV of synchrotron radiation with the critical energy of 1.62 MeV. Due to bending of the electron beam by the SB prior to the entry into the HB, there is 1 mrad separation between the direction of the neutral beam (Compton photons) and the beginning of the HB synchrotron stripe, which gives a 9 mm displacement at the location of the QFC detector. Tungsten absorber plates are shaped to avoid being hit by the HB synchrotron photons. However, due to very limited space available for the QFC it had to be placed near beam pipe flanges and a collimator, which scatter synchrotron radiation onto the detector. Our studies showed that this radiation is the major source of the background seen by the QFC.

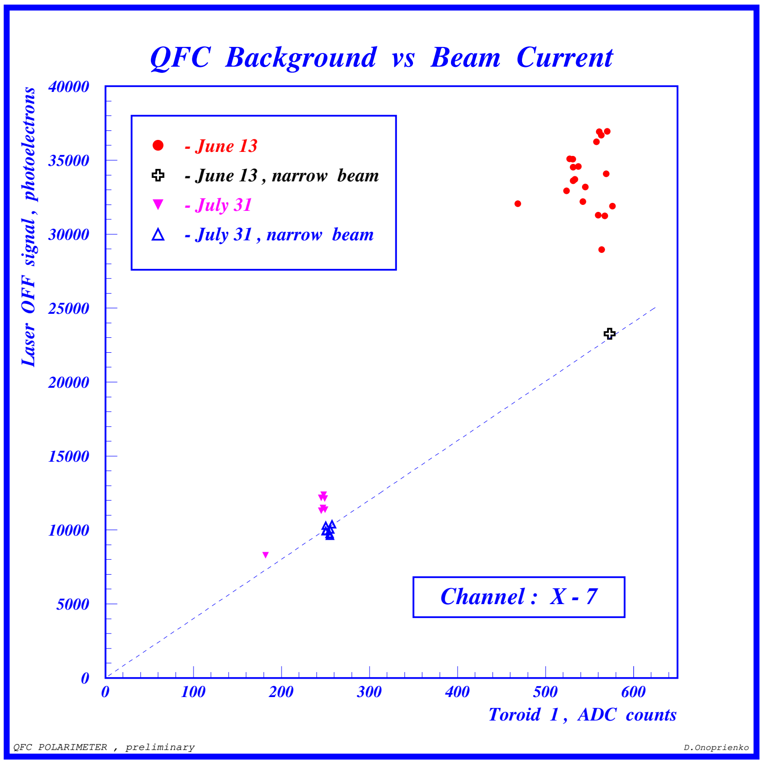

Fig. 3 Dependence of the QFC background level on the electron beam current. Each point represents a 3-minute polarimeter run.

Twice during the run, on June 13 and July 31, we took data in the "narrow beam" mode - with Q16.5 quadrupole in the North Final Focus (NFF) running at low current, shifting the beam focus from the SLD IP and providing 5-7 times smaller beam size through the South Final Focus (SFF). Analysis of the data taken in this mode brought us to the conclusion that with the "narrow beam" almost all the background observed by the QFC comes from the scattered HB synchrotron stripe - the only source that is consistent with the behavior exhibited by the QFC backgrounds in this mode :

- Magnitude of the background scales with the electron beam current (figure 3).
- Both magnitude and RMS of the QFC background are insensitive to the beam steering - they did not change significantly even when the beam setup was a way off nominal, causing huge increase in the background observed by the Ĉerenkov electron spectrometer.
- Switching off or lowering all the upstream quadrupoles in the SFF did not have any visible effect on the QFC backgrounds, ruling out synchrotron radiation in these quads as a possible source.

In the nominal beam mode, there is an additional part of the background (figure 3) which shows strong dependence on the beam steering - most likely it is produced by the beam tails scratching collimators and generating synchrotron radiation in upstream quadrupoles, although we could not identify the exact source due to very limited time available for QFC studies. While being much smaller in magnitude, this background is highly variable and makes a significant contribution to the statistical error, especially in X-channels (horizontal fibers). When the QFC removable 4 inch lead shutter is inserted in front of the calorimeter, this part of the background is largely eliminated - both magnitude and RMS of the background seen by the detector in this configuration are close to what was observed in the "narrow beam" mode.

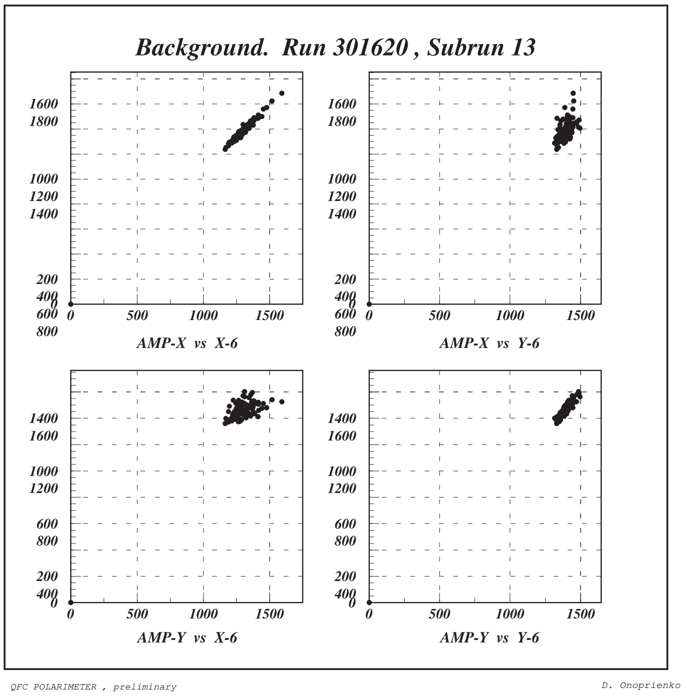

Fig. 4 Correlations between background signals in different channels.

To check what part of the background is picked up by transport fibers between the calorimeter and the PMT box, we placed an extra photo-tube in the box with a bunch of fibers going all the way to the calorimeter along the same path as readout fibers but not connected to the calorimeter. Comparing signals from this ”Calibration channel” and from other channels, we found that at least half of the background is picked up in this transport region.

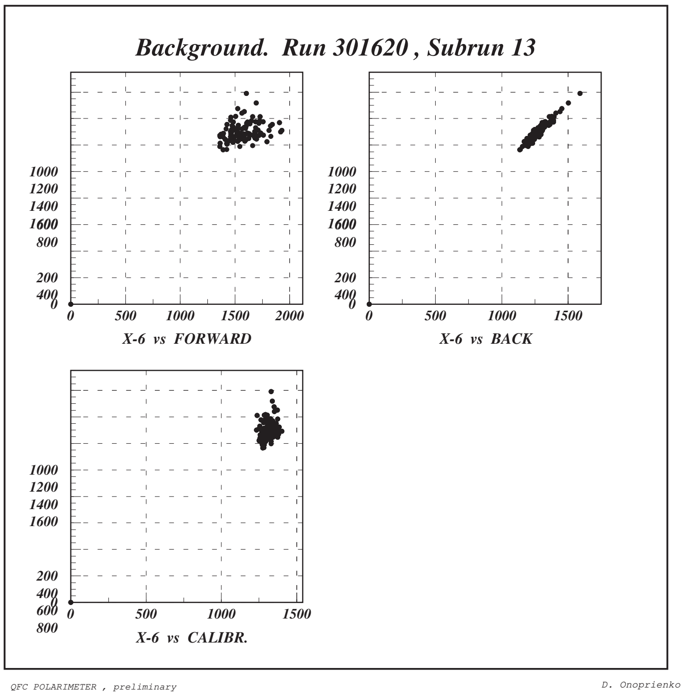

Fig. 5 Correlations between background signals in different channels. Note that “Forward Background” channel fibers go in Y-direction, while “Back Background” fibers go in X-direction.

Looking into correlation between background signals in various channels on pulse-by-pulse basis, we found that very strong correlation exists between any two X-channels, or any two Y-channels, while, after removing the dependence on the beam current, there is little correlation between X and Y channels, and in no other channel the signal is correlated with the signal in the ”calibration channel” (figure 4,5). This indicates that the background signal picked up by the quartz fibers inside the calorimeter aluminum body but outside the tungsten absorber (in this region region all X-fibers go along the same path, as well as all Y-fibers, but these two paths are very different) accounts for a significant part of the background fluctuations.

4 Monte-Carlo Simulation

The results described above suggest that the QFC backgrounds can be greatly reduced by additional shielding, particularly by shielding the fibers outside the tungsten absorber. To verify our conclusions and to optimize the design of such shielding, the background caused by the scattered HB synchrotron stripe was simulated in details by GEANT.

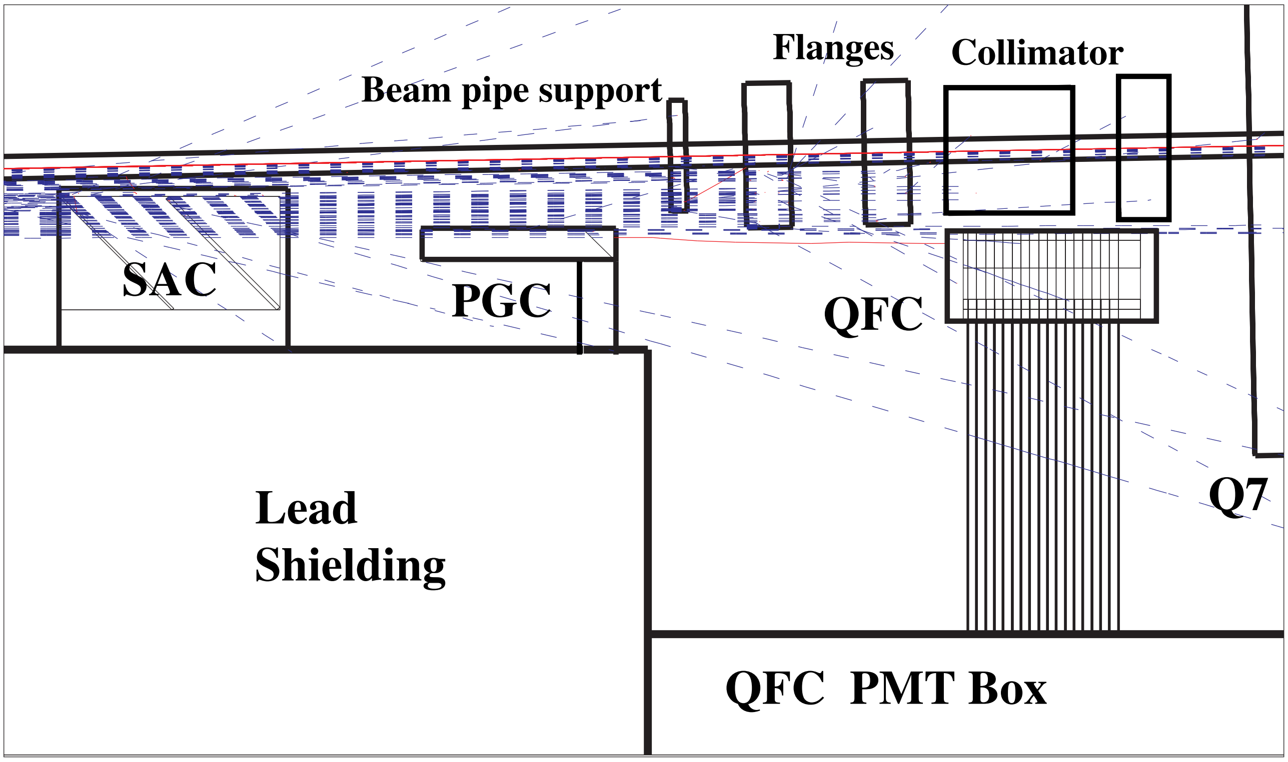

Fig. 6 Simulated geometry.

The simulated geometry (figure 6) includes SB and HB magnets, exit window, beam pipe with its support, steel flanges and collimator, SAC and PGC counters with removable pre-radiators, QFC removable lead shutter, Q6.5 and Q7 quadrupoles, and the QFC. The electron beam originates from the Compton IP and produces synchrotron radiation in the magnets. The detector response was assumed to be proportional to the number of hits in each quartz fiber by charged particles above the Ĉerenkov threshold. Actual Ĉerenkov light production and light transport simulation is being implemented now and will be used to study various factors affecting the systematic error of the polarization measurements. For the purpose of background simulation, current scheme proved to be sufficient, giving good qualitative agreement between data and Monte-Carlo.

Table 1 compares the results of the simulation for nominal '96 run geometry with the data taken in the “narrow beam” mode (when, according to our conclusions, almost all the QFC background is due to scattered HB synchrotron radiation).

Parameter	Data	Monte-Carlo
Signal-to-noise ratio assuming 1000 Compton photons per pulse, central Y-coordinate channel	1:29	1:28
Signal-to-noise ratio assuming 1000 Compton photons per pulse, Y-amplitude channel	1:115	1:101
Background RMS-to-magnitude ratio, central Y-coordinate channel	2.56 %	1.73 %
Background RMS-to-magnitude ratio, Y-amplitude channel	2.32 %	1.58 %
Ratio of background signals per fiber per bunch in X-coordinate and "Back Background" channels	2.15	1.85
Ratio of background signals per fiber per bunch in Y-coordinate and "Back Background" channels	1.72	1.71
Ratio of background signals per fiber per bunch in X-amplitude and "Back Background" channels	2.05	2.16
Ratio of background signals per fiber per bunch in Y-amplitude and "Back Background" channels	1.44	1.99
Ratio of background signals per fiber per bunch in "Forward Background" and "Back Background" channels	3.63	5.06

Table 1
Comparison of the results of the Monte-Carlo simulation for nominal '96 run geometry with the data taken in the "narrow beam" mode

The effects of inserting PGC or QFC removable lead in front of the calorimeter look very similar in data and Monte-Carlo, though only rough comparison is possible - we do not have any data taken in the "narrow beam" mode with lead in the neutral beam.

To figure out what shielding configuration might be most effective, backgrounds picked up by quartz fibers in three different regions were calculated separately. The results are shown in table 2.

Only small part of the background signal is generated inside the tungsten absorber (region 1, calorimeter proper), while region 2 (outside tungsten but inside the calorimeter aluminum body) and region 3 (transport fibers between the calorimeter and the PMT box) are responsible for most of the QFC background. Therefore, improved shielding in these regions is especially important.

5 Shielding design for the '97 run

The QFC shielding design was optimized using the Monte-Carlo simulation described above. Two general principles proved to be most effective in reducing the background :

- Shield fibers in the transport region between the QFC absorber and the PMT box.
- Intercept the HB synchrotron stripe as far upstream as possible, before it hits the beam pipe flange.

Channel	Region 1	Region 2	Region 3
X - coordinate	5.4	14.0	80.6
Y - coordinate	11.4	29.7	58.9
X - amplitude	7.5	13.4	79.1
Y - amplitude	16.0	27.9	56.1
Forward background	29.9	23.9	46.2
Back background	8.6	8.6	82.8

Table 2
QFC background picked up by fibers in various regions, per cent. Region 1 is the calorimeter proper - inside the tungsten absorber. Region 2 is outside tungsten but inside the calorimeter aluminum body. Region 3 is between the calorimeter and the PMT box.

Various shielding configurations have been tried, and the best design yielded signal-to-background ratio of 4:1 in a central coordinate channel (more than two orders of magnitude improvement compared to the '96 run geometry). However, there is a concern that building such shielding might increase Compton electron spectrometer backgrounds by scattering HB synchrotron radiation and beamstruhlung onto it [6]. To avoid this problem, we decided not to install any shielding upstream from the downstream edge of the Ĉerenkov detector (electron spectrometer), and the rest of the QFC shielding was designed in modules that can be installed and removed independently. Table 3 lists available shielding options and expected signal-to-background ratio for each of them.

Options 1 and 2 do not interfere in any way with the Ĉerenkov detector operation. Option 3 might have an effect on the spectrometer backgrounds.

The following scenario has been suggested for the '97 run :

- We start running with option 1, commission the calorimeter and verify its alignment with the beam. This can be done parasitically during the SLC tune-up. We might also request 1 hour of running in the "narrow beam" mode if necessary.
- Whenever access to the SFF tunnel is possible we switch to option 2. Estimated access time necessary to complete this work is 1 hour.
- If the background observed with option 2 is acceptable, we will run in this configuration for the rest of the run. If not, we will try to switch to option 3 and see what effect it has on the Ĉerenkov detector backgrounds. It might be possible to use this shielding option for QFC

dedicated running only.

Option	Description	Background reduction factor
1	Available space inside the calorimeter aluminum body is filled with tungsten. Lead shielding around transport fibers between the calorimeter and the PMT box. Lead shielding above and behind the calorimeter.	2.0
2	In addition to the option 1, tungsten shielding with a collimator hole is installed in front of the calorimeter. Fills the region between the downstream edge of the PGC counter and the front face of the QFC.	7.4
3	In addition to the option 2, shielding is installed under and beside the PGC counter to intercept the HB synchrotron stripe.	69.1

Table 3
Available shielding options and expected reduction in the level of the background, compared to the '96 run.

As we mentioned above, the Monte-Carlo simulation only takes into account the part of the background coming from the scattered HB synchrotron stripe. To achieve the desired level of the QFC performance, it is also important to reduce the other part of the background, which is much less in magnitude but contributes significantly to the background fluctuations. As described in the section on the background studies during the '96 run, most of this part was picked up by the fibers outside the calorimeter absorber, and it was greatly reduced by inserting the lead shutter in front of the QFC. Therefore we expect that current shielding with a collimator in front of the detector and protected transport fibers will also do this job. However, if the background from the scattered HB synchrotron radiation is reduced as expected, other sources might become most significant. For this reason, it is important to tune the accelerator to minimize the QFC backgrounds before taking data with this detector.

6 Conclusion

The modified QFC, together with its new calibration system and shielding, has been installed in the SFF and prepared for the SLD '97 run. Two shifts of dedicated electron-only beam running have been requested from the collaboration, which should be enough to tune up the system and produce the longitudinal polarization measurement with statistical error below 1 %, based on '96 run performance under good beam conditions. With expected improvement in the level of background even better accuracy can be achieved, giving us an extremely important cross-check of the measurement by the existing Ĉerenkov electron spectrometer with different and very low systematic uncertainty. Unlike other detectors, the asymmetry measurement by the QFC does not rely heavily on calibration by Monte-Carlo simulations, and has very low sensitivity to the detector alignment errors. LED calibration system [7] allows a high precision check of the readout linearity and channel-to-channel calibration.

To make room for the new shielding, the QFC moving support had to be removed for the '97 run. This has no effect on the longitudinal polarization measurement, but because the detector position scans are now impossible, we will not be able to measure the transverse polarisation with the accuracy better than 4 %.

After taking the electron beam data, we plan to remove the detector from the SFF and bring it to the FFTB for a beam test. This would be particularly useful for verifying our current estimate for the systematic error of the polarization measurement.

7 References

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