**DRAFT 3!**

# Møller Polarimetry in the $G^0$ Experiment

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**Abstract**

This technical note describes the Møller polarimetry in the second engineering run and the forward-angle physics data run of the $G^0$ experiment (E00-006) in Hall C at Thomas Jefferson National Accelerator Facility from November 2003 through May 2004. This note covers the Møller apparatus, the longitudinal polarization measurements performed during the experiment, the spin-dance studies done to select the proper Wien angle for the maximum longitudinal polarization and transverse polarization, the effect of Hall A and B leakage on the Hall C beam polarization, the analysis of the polarization data, and the final polarization numbers and plots for the forward angle physics data.

## Contents

**Introduction** **2**

**The Polarized Electron Beam at Jefferson Lab** **2**
The Generation of Polarized Electron Beams . . . 2
Beam Transport and Spin Precession . . . 3

**The Hall C Møller Polarimeter** **4**
Møller Scattering . . . 4
The Møller Polarimeter Apparatus . . . 4
Longitudinal Polarization Measurements . . . 5
Spin Dance Measurements . . . 6
Transverse Polarization Measurements . . . 7
Leakage Polarization Measurements . . . 7

**Analysis of the Polarization Data** **8**
Transverse Polarization Analysis . . . 8
Longitudinal Polarization Analysis . . . 8
Polarization Stability Studies . . . 9
Møller Systematic Error . . . 10
Final Beam Polarization Results . . . 12

**A Polarization Measurements** **15**

**B Leakage Polarization Measurements** **18**

**C Spin Dance Polarization Measurements** **19**

**D Justification of Polarization Time Periods** **22**

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# Introduction

For a parity-violation experiment such as the $G^0$ experiment, it is very important to know the polarization of the electrons in the beam. In order to extract the physics asymmetry from the experimentally measured asymmetry, it is necessary to correct the measured raw asymmetry value for the longitudinal beam polarization, as well as other dilution factors. The physics asymmetry $A_{physics}$ is related to the measured asymmetry $A_{measured}$ and the polarization $P^B$ by

$$A_{physics} = \frac{A_{measured}}{P^B}.$$

There is an additional additive correction factor that contributes from any residual transverse beam polarization. Although only the longitudinally-polarized electrons contribute to the parity-violating asymmetry that we are interested in, any transverse beam polarization is a potential source of false asymmetry since the transversely-polarized electrons can contribute to a parity-conserving Mott asymmetry. Unlike the parity-violating asymmetry, this is a left-right asymmetry, but it does contribute if the detector is not completely symmetric about the axis of the transverse electron polarization. This left-right asymmetry arises from the transverse electron spin interacting with the current generated by the proton's movement in the electron rest frame (two-photon exchange effect) [1]. The correction $K_T$ to the parity-violating asymmetry can be written as

$$K_T = A_T \frac{P^B T}{P^B} F_S,$$

where $A_T$ is the measured asymmetry for purely transversely polarized beam, $P^B T$ is the transverse beam polarization, $P^B$ is the total beam polarization, and $F_S$ is the degree of detector asymmetry [2]. A measurement of the transverse component of the electron beam polarization is clearly needed to constrain the size of this systematic false asymmetry, so a series of measurements with transversely polarized beam were performed to extract $A_T$. The generation and indirect determination of the transversely polarized beam are discussed in this note; the discussion of the contribution of the transverse component of the beam to a systematic false asymmetry is located in another technical note [3].

In addition to these concerns, it is by using the beam polarization data from the Møller polarimeter that we choose the optimal Wien filter angle setting to compensate for the beam spin-transport through the accelerator and thus obtain the maximum possible longitudinal polarization in the experimental hall. The sign of the polarization data is also used to determine the actual electron orientation in the two designated helicity states for each insertable half-wave plate setting. The measurements performed to optimize the Wien filter angles are discussed in this report; for more information about the determination of the true electron helicity, refer to the separate technical note covering that topic [4].

Happily, Hall C is equipped with a Møller polarimeter that is able to measure the polarization of the electron beam to great accuracy. Although the Hall C Møller cannot directly measure the transverse beam polarization, it was possible to indirectly infer the transversely-polarized component of the beam.

# The Polarized Electron Beam at Jefferson Lab

The $G^0$ experiment typically made use of 40 $\mu$A of a 3 GeV polarized electron beam delivered into experimental Hall C by the accelerator at Jefferson Lab. The polarized electron beam available at Jefferson lab is very clean, with little beam halo and small helicity-correlated differences in beam properties such as charge, position, and angle, making the lab the ideal place to conduct a precision parity-violation measurement like $G^0$.

## The Generation of Polarized Electron Beams

The highly polarized electron beam produced at Jefferson Lab is produced by shining circularly polarized laser light onto a strained gallium arsenide (GaAs) crystal. The circularly polarized laser light is generated from the linearly polarized light from the titanium(Ti)::sapphire $G^0$ laser by a Pockels cell. A Pockels cell is a birefringent crystal where the indices of refraction vary in direct proportion to the voltage applied to it. The voltage applied to it effectively makes the Pockels cell a $\lambda/4$ (quarter-wave) plate, which converts the linearly polarized laser light into left- or right- circularly polarized light. When the circularly-polarized

laser light is made incident on the GaAs crystal, electrons escape the crystal via the photoelectric effect, and have a net polarization due to incident photon's polarization and the allowed transitions in the GaAs crystal. The choice of left- or right- circularly polarized light incident on the the GaAs crystal determines the helicity state, "$h^+$" or "$h^-$", of the emitted electrons [2].

The helicity signals for the experiment are generated in quartets: $+--+$ or $-++-$, where the first member of the quartet is chosen pseudo-randomly and the next member is the complement of the first. The electron helicity is flipped every 30 ms, or macro-pulse (MPS). This scheme allows a cancellation of linear drifts over the timescale of the quartet sequence. The helicity information signals a transition at the instant the Pockels cell is set to the new state, and then the signals "$h^+$" and "$h^-$" are sent to the $G^0$ electronics in the Hall C counting house from the polarized source helicity control box in "delayed reporting mode" (delayed by a present number of 30 Hz pulses) [5]. These signals are used to designate the helicity of a given MPS, although the labels "$h^+$" and "$h^-$" only describe the helicity state and its complement, respectively, and do not necessarily contain the state that the label implies.

As a systematics check, the $G^0$ experiment uses an insertable half-wave plate (IHWP) on the laser table. The insertion of this IHWP reverses the helicity of the beam electrons with respect to the helicity signal reported to the $G^0$ electronics, so that the electrons labeled as "$h^+$" are flipped to the opposite helicity state that they were formerly. The parity-violating physics asymmetry reverses sign, but the electronics asymmetry does not under the insertion or removal of the IHWP. Since all other aspects of the experiment have remained the same, any helicity-correlated differences in the electronics become apparent when physics asymmetries from data taken with the IHWP in and out are summed together. If there are no helicity-correlated differences present in the electronics, the physics asymmetries summed over the two IHWP states will be zero. As the polarization reported by the Møller analyzer is calculated from the Møller asymmetry measured by the polarimeter, the sign of the Møller asymmetry also changes sign with the IHWP setting. This causes the polarization to be reported as positive or negative, depending on the actual helicity of the beam electrons in that IHWP setting.

## Beam Transport and Spin Precession

The electrons that are emitted from the GaAs crystal are longitudinally polarized. However, as the electron beam is transported through the accelerator to Hall C, the beam is bent by a series of dipole magnets that cause the beam polarization to precess relative to the momentum vector due to the anomalous magnetic moment of the electron. This rotation happens because the gyro-magnetic ratio of the electron is 2.0023193, instead of precisely 2. To compensate for the $g-2$ precession and ensure that the electrons that arrive at the $G^0$ target are longitudinally polarized, the beam passes through a Wien filter before the beam enters the accelerator.

The Wien filter consists of a pair of electrostatic plates and a magnetic dipole. The electric field from the plates is perpendicular to the magnetic field from the dipole, and both are perpendicular to the beam velocity. The electric and magnetic fields are set to cancel each other out, that is, the net Lorentz force on the electrons must be zero:

$$\mathbf{F} = q(\mathbf{E} + \vec{\beta} \times \mathbf{B}) = 0,$$

where $\vec{\beta} = \frac{\mathbf{v}}{c}$ is the electron velocity, and $\mathbf{E}$ and $\mathbf{B}$ are the electric and magnetic field vectors, respectively. Since there is no net force on the beam electrons, the trajectory of the beam is unchanged as it passes through the filter. However, the spin vector of the electron will precess about the magnetic field. The precession is given by [6], [2]:

$$\frac{d\mathbf{s}}{dt} = \frac{e}{mc}\mathbf{s} \times \mathbf{B}\left[\frac{g}{2}(1+\beta^2) - 2\left(1 - \frac{1}{\gamma}\right)\right],$$

where $\mathbf{s}$ is the electron's spin vector, $\frac{g}{2}$ is the magnetic moment of the electron in units of Bohr magnetons $\left(\mu_B = \frac{e\hbar}{2m_e}\right)$, and $\gamma = \frac{1}{\sqrt{1-\beta^2}}$. Assuming a perfect Wien filter of length $L$, the total spin rotation angle is given by

$$\theta = \frac{L}{c\beta}\frac{eB}{mc}\left[\frac{g}{2}\left(1+\beta^2\right) - 2\right].$$

The optimization of the Wien filter setting is done experimentally by using the Møller polarimeter to perform a spin-dance measurement, but it can be roughly set by using the knowledge of the beam energy and precession through the accelerator.

# The Hall C Møller Polarimeter

## Møller Scattering

The Møller polarimeter is used to measure the polarization of the electron beam entering Hall C. To accomplish this goal, the polarimeter measures the spin-dependent asymmetry in the cross section for the elastic scattering of polarized electrons from polarized electrons ($\vec{e} + \vec{e} \rightarrow e + e$), or Møller scattering. The cross section asymmetry for Møller scattering can be calculated exactly in quantum electrodynamics. For a longitudinally-polarized (in the $z$-direction) beam and target, the cross section in the center-of-mass (CM) reference frame is given by [7]:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_\circ}{d\Omega} \left\{1 + P_z^B P_z^T A_{zz}(\theta)\right\},$$

where $\frac{d\sigma_\circ}{d\Omega}$ is the unpolarized cross section, $A_{zz}(\theta)$ is the analyzing power, and $P_z^B$ and $P_z^T$ are the beam and target foil longitudinal polarization, respectively.

The asymmetry for the cross-sectional difference between right-handed and left-handed incident beam electrons can be computed by the expression [7]

$$A_{Møller} = \frac{\left(\frac{d\sigma}{d\Omega}\right)^{\uparrow\uparrow} - \left(\frac{d\sigma}{d\Omega}\right)^{\downarrow\uparrow}}{\left(\frac{d\sigma}{d\Omega}\right)^{\uparrow\uparrow} + \left(\frac{d\sigma}{d\Omega}\right)^{\downarrow\uparrow}} = |P_z^B||P_z^T|A_{zz}(\theta),$$

At $90^\circ_{CM}$, the analyzing power is large ($A_{zz}(\theta) = -\frac{7}{9}$), and with a known target polarization $P_z^T$, a determination of the beam polarization can be made by measuring $A_{Møller}$.

## The Møller Polarimeter Apparatus

The Hall C Møller polarimeter measures the absolute polarization of the electron beam that arrives in Hall C with an accuracy of better than 0.5%. The polarimeter is located in the Hall C beam alcove, which is upstream of the entrance to Hall C, but downstream of the last dipole magnets that steer the electron beam into Hall C from the beam switchyard. This location ensures that there will be no further polarization changes due to spin precession caused by beam transport before the electron beam reaches the $G^0$ target in Hall C.

A schematic of the polarimeter apparatus is shown in Figure 1. The Møller target that the experiment used for the typical polarization measurement was a 4 $\mu$m thick iron foil target that was magnetized by a 3 T magnetic field produced by the superconducting Møller solenoid. The high magnetic field ensures a complete saturation, so the spin polarization of the outer shell target electrons in the target is well known ($8.036 \pm 0.015\%$). The target foil is mounted in a remotely controlled target ladder that is used to insert or retract the desired target into or out of the beam path. The Møller electrons that scatter at $90^\circ_{CM}$ ($1.06^\circ$ in the lab frame at the 3 GeV beam energy for $G^0$) pass through a small quadrupole, a series of densimet (a tungsten alloy) collimators, and a large quadrupole magnet to achieve a satisfactory separation of the scattered Møller electrons and the beam line (a horizontal spread of 49 cm). The system of movable collimators and the pair of quadrupoles allows the system to be tuned for different beam energies from about 0.8 to 6 (GeV/c)$^2$. In order to suppress the Mott background, the Møller polarimeter uses two lead glass total absorption detectors in coincidence. The narrow coincidence time gate (5 ns width) reduces the accidental background and the shower counters, which provide energy information, allow the suppression of any low-energy background. A Møller electron pair is defined as a coincidence between both the left and the right lead-glass shower counters. Møller electrons separated 43 to 55 cm from the beam line (which corresponds to $83^\circ_{CM}$ to $97^\circ_{CM}$) are accepted past the collimators that are placed directly in front of the lead-glass detectors [7]. A diagram of the position of the collimators and quadrupoles is shown in Figure 2.

## Polarization Measurements

The majority of the measurements made with the Møller polarimeter were to determine the longitudinal polarization of the electron beam. However, the Møller was also used to determine the optimal Wien angle setting for the longitudinal running, as well as the optimal setting for the transverse polarized running.

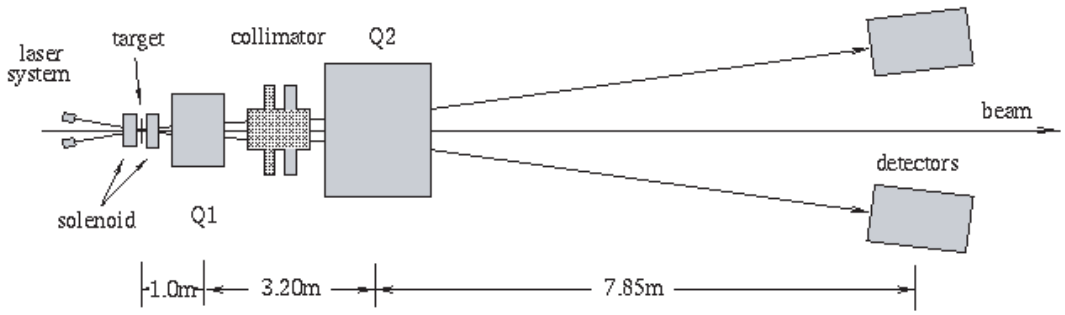


Figure 1: *A diagram of the Hall C Møller polarimeter.*

From this, the transverse polarization could be indirectly determined. Some polarization measurements of the leakage beam from the Hall A and B lasers were also performed.

**Longitudinal Polarization Measurements**

Typically, polarization measurements were performed when the insertable half-wave plate setting was changed, or about every two or three days in the $G^0$ experiment. The procedure for taking data with the Møller polarimeter is simple, and was even more so for the $G^0$ experiment, since the experiment ran with the Møller quadrupoles on and part of the nominal beam optics. Directly before a measurement, while normal physics data-taking was proceeding, the injector parameters were recorded to verify that the Møller data were taken in a state as close to normal $G^0$ production data-taking conditions as possible. After recording the injector parameters and the state of the beam to the other two experimental halls, the person performing the measurement would contact the machine control center (MCC), requesting that the accelerator operators tune the beam for a Møller measurement in Hall C. MCC would turn off the beam and the $G^0$ target would be retracted. The Møller solenoid was usually left ramped up to the operating field of 3 T for most of the data run, but if necessary, the Møller solenoid was ramped up to the operating field at this point. In this interval, the high voltage to the $G^0$ main detectors and halo monitors would be turned off, the high voltage to the Møller detectors would be turned on, and the gain setting for BCM2 (a beam current monitor) would be switched up to gain setting 4 from 3. MCC would then tune the beam and adjust the beam positions for the Møller measurement. After the beam positions were acceptable, MCC would turn off the beam and Møller target 3 (the 4 $\mu$m thick iron foil target) would be inserted into the beam path. The person performing the measurement would then request 2 $\mu$A of beam. The current for these measurements was reduced using the slit, so the leakage fraction remains the same at 2$\mu$A and 40 $\mu$A. After verifying that the Møller scalers were all counting at a coincidence rate of about 10 - 100 kHz, the Møller operator would start the Møller data acquisition system. A typical Møller data run for the $G^0$ experiment was about 5 minutes long and would have at least 5 million coincidences. While the Møller data were being taken, the injector parameters were recorded again to compare to the usual $G^0$ running conditions. After taking two or three data runs, the person doing the Møller measurement would ask MCC to change the half-wave plate setting, and then would take two more Møller data runs. After each run finished, the Møller operator replayed the run with the Møller analyzer to verify that the beam polarization and the sign of the beam polarization were as expected. After finishing the measurement, the Møller operator would reverse the set-up steps to restore the normal running conditions and record the results of the measurement in the $G^0$ electronic logbook.

Tables that list all of the polarization measurements performed during the second engineering run and the forward-angle physics run of the $G^0$ experiment are included in Appendix A.

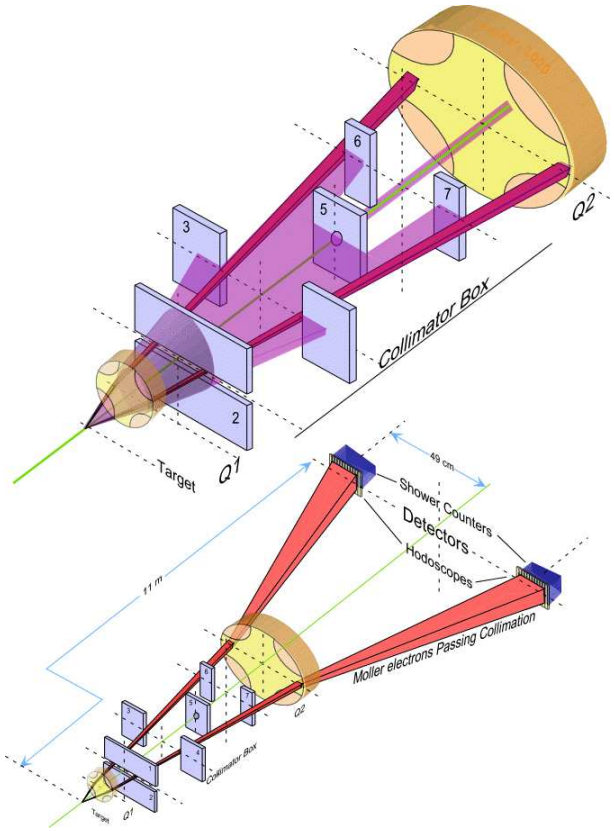


Figure 2: *A diagram of the Møller lay-out and optics.*

**Spin Dance Measurements**

Because of the spin precession that takes place during beam transport to Hall C, it is necessary to calibrate the Wien filter to the optimal setting that will maximize the longitudinal polarization at the $G^0$ target. Since the Møller polarimeter is located after the last of the major bending magnets that steer the beam into Hall C, it is used to perform this calibration.

To perform the calibration, data were collected with the Møller polarimeter for several Wien angle setting spanning about 200°. The polarization of the beam at each Wien angle setting was determined from the measured data, and then plotted versus the Wien angles. The data showing the dependence of the measured polarization on the Wien angle was fitted using

$$P_{meas} = P_e \cos(\eta_{Wien} + \phi),$$

where $P_e$ is the beam polarization amplitude, $\eta_{Wien}$ is the Wien angle setting, and $\phi$ is the net spin rotation between the Wien filter and the Hall C polarimeter. From the fit, the net spin rotation $\phi$ at the maximum longitudinal polarization can be found, and the Wien filter can be set to the negative of this value to compensate for the spin rotation. An example of the data and the fit using the data from the February 10, 2004 spin dance is shown in Figure 3. after the spin dance, the Wien angle was set to $-12.62°$ to maximize the longitudinal polarization [8].

Ideally, the Wien filter setting should remain the same throughout an experiment if nothing else changes in the beam path. However, due to a pass/energy configuration change and the transverse data-taking, other spin-dance measurements were required and the Wien angle settings were adjusted several times during the $G^0$ experiment.

Tables that list all of the spin-dance polarization measurements performed at each spin-dance during the second engineering run and the forward-angle physics run of the $G^0$ experiment are included in Appendix C, along with the plots and fits to the data.

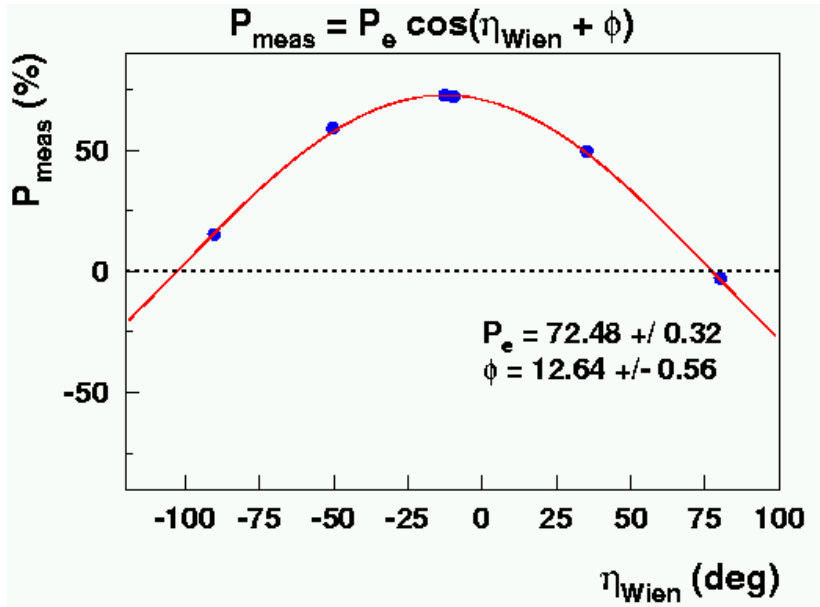


Figure 3: *A fit of the form $P_{meas} = P_e \cos(\eta_{Wien} + \phi)$ to the polarization data from the February 10 spin dance.*

**Transverse Polarization Measurements**

The Hall C Møller polarimeter is unable to directly measure the transverse polarization since it does not at present have the capacity to have a transversely-polarized target. However, an indirect determination of the transverse component of the polarization can be made by constraints set by a spin dance.

By doing the sinusoidal fit to the measured polarization data at the different Wien angles and solving for the zero-crossings, the two Wien angles for purely transversely polarized beam were ascertained for the transverse running of $G^0$. To verify the Wien angle setting, polarization measurements were then taken. A longitudinal polarization measurement with the Hall C Møller polarimeter that is consistent with zero implies that the polarization is purely transverse. In the spin dance for the $G^0$ transverse running on March 22, the measurements gave an optimal longitudinal Wien angle of +3.69 degrees and two zero-crossings for the optimal transverse polarization at -84.99 and +93.90 degrees. The Wien was set to -85.23 degrees, which yielded a longitudinal polarization measurement consistent with zero, as expected. However, it was found that in the four days of transverse running, the spin direction of the polarization relative to purely longitudinal had drifted $2.75^\circ \pm 0.50(\text{stat}) \pm 0.55(\text{sys})$, when the March 26 spin dance measured a zero crossing of $-87.98^\circ \pm 0.71$ [9].

Tables that list the polarization measurements, including the indirect transverse measurements, performed during the second engineering run and the forward-angle physics run of the $G^0$ experiment are included in Appendix A.

**Leakage Polarization Measurements**

During the experiment, polarization data were taken to determine the effect of the leakage beam current from Halls A and B on the Hall C polarization. These data were were taken at different slit settings and different configurations of the other two halls, and were taken throughout the run.

One of the studies was performed to ascertain the worst-case scenario of the effect of the leakage current on the polarization in Hall C. To do this, the current was changed using the attenuator instead of the slit, and the slit was set wide open. This gave the maximum sensitivity to the leakage current from halls A and B. It was determined that even with Hall A running at 120 $\mu$A and Hall B at 25 nA, the leakage current was quite small, about 50 nA. The effect of this leakage was to drop the measured polarization by about 3% at 2 $\mu$A with the Hall C slit wide open using the attenuator instead of the slit. From this information it can be determined that when taking data at 10 $\mu$A, the leakage current decreases the beam polarization by about 0.6%, at 20 $mu$A by 0.3%, and at 40 $\mu$A it drops by about 0.15%, assuming the the current is changed using the attenuator [10]. Under normal data-taking conditions, using the slit instead of the

attenuator to change the current, the maximum possible effect from the leakage was 0.2% (fractional) on the polarization.

Tables that list the leakage beam polarization measurements performed during the second engineering run and the forward-angle physics run of the $G^0$ experiment are included in Appendix B.

# Analysis of the Polarization Data

## Transverse Polarization Analysis

The determination of the transverse polarization was done by assuming that the longitudinal polarization measured for the spin dance on March 26 was the value of the polarization during the transverse running. The error bars were assigned based on the interpolation between the two spin dances on March 22 and 26, with some inflation due to the indirect nature of the determination and the drift of 2.75 degrees that occurred during that period. People using these transverse numbers may wish to assume some additional systematic uncertainty since the transverse polarization was not directly measured.

Based on the constraints from the spin dance, the interpolated polarization values for the transverse running are shown in Table 1.

| Run Range | Polarization (%) | IHWP | Time Period | Comments |
|---|---|---|---|---|
| 20791-20900 | $74.18 \pm 0.74$ | in | 3/22 - 3/26 | Transverse |
| 20791-20900 | $74.45 \pm 0.74$ | out | 3/22 - 3/26 | Transverse |

Table 1: *The absolute polarization for the transverse running. Error bars are quasi-statistical with some interpolation error folded in*

## Longitudinal Polarization Analysis

The beam polarization value is calculated by the equation

$$P_z^B = A_{M\o l} \times f_B,$$

where $A_{M\o l}$ is the measured Møller asymmetry defined by

$$A_{M\o l} = \frac{h_+ - h_-}{h_+ + h_-},$$

and $f_B$ is the beam polarization factor. The beam polarization factor is defined as

$$f_B = \frac{1}{P^T \overline{A_{zz}}},$$

where $P^T$ is the target polarization and $\overline{A_{zz}}$ is the analyzing power integrated over the entire acceptance of the Møller detectors. $\overline{A_{zz}}$ is generated by the Møller Monte Carlo, and includes the corrections for multiple scattering, radiative corrections, and the Levchuk effect (atomic Fermi motion). In principle, it gives what would be measured if the beam was 100% polarized. The error on the beam polarization is given by [7]

$$\frac{\Delta P^B}{P^B} = \sqrt{\left(\frac{\Delta A_{M\o l}}{A_{M\o l}}\right)^2_{stat} + \left(\frac{\Delta \overline{A_{zz}}}{\overline{A_{zz}}}\right)^2_{sys} + \left(\frac{\Delta P^T}{P^T}\right)^2_{stat+sys}}.$$

The polarization was high and very stable throughout the running of the $G^0$ experiment. However, changes in the source, such as laser spot moves and injector configuration changes, had an impact on the measured polarization in Hall C. In addition, there is suggestive evidence that changes to the PITA voltage may have had some impact on the polarization. The time length of the run was divided into periods defined by changes in the source that affected the measured polarization, and the final values are reported based on these intervals of stable beam. Other factors that affected the were leakage from the other halls, which was measured and corrected, and potential mis-settings of the Wien filter, which are discussed later.

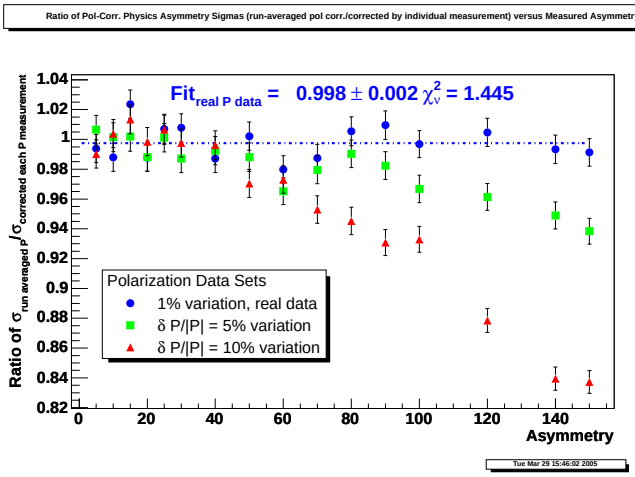


Figure 4: *A plot of the ratio of the sigmas from the two polarization correction methods versus measured asymmetry.*

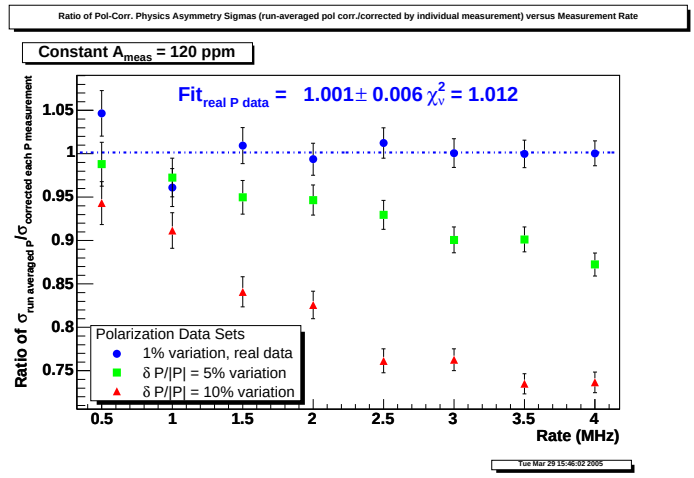


Figure 5: *A plot of the ratio of the sigmas from the two polarization correction methods versus the rate.*

### Polarization Stability Studies

The beam polarization was extremely stable for the period of the $G^0$ physics data run. The question of just how stable was then posed to ascertain whether the physics asymmetries had to be corrected for the polarization on a run-by-run basis by the nearest polarization measurement, or could be corrected by the global average polarization value for the entire physics run. To make this determination, a simple study by simulation was done.

A simulation of the data-taking was set up, using the assumptions that the rate was 1 MHz and that a polarization measurement was taken every 47 hours, or about two days. The program calculated the polarization-corrected asymmetry for that period and a given measured asymmetry, and then used this information to randomly fill a Gaussian distribution for a measurement using eight octants for 47 hours. This was done for fifteen polarization measurements. The fifteen Gaussian of the corrected measurement from each period were summed, and then fitted. This was done for a range of measured asymmetries varying from 5.0 to 150.0 ppm.

This was repeated for three different polarization data set: the first fifteen average measurements from the real data set, which has about a 1% variation, a fabricated set with a 5% symmetric variation, and a seoond fabricated set with a 10% symmetric variation. The variation of the two fabricated polarization data sets was chosen to be symmetric (with the last value left untouched since the set has an odd number of measurements) so that the mean polarization value for the run would be the same for all three sets.

The simulation also calculated the polarization-corrected asymmetry using the global average polarization of the fifteen measurements from the entire run and a given measured asymmetry for the entire physics run, and the used that information to randomly fill a Gaussian distribution for a measurement of 705 hours using all eight octants. The resulting Gaussian was fitted, just as in the case before. This was also done for the same sixteen measured asymmetry values and three polarization data sets, although the mean value for each polarization set was identical.

The results from this exercise are shown in Figure 4. Figure 4 is a plot of the sigma from the fit of the Gaussian of the run-averaged polarization-corrected asymmetry divided by the sigma from the fit of the individual measurement-corrected Gaussian versus the varied asymmetry values, for each of the three polarization data sets. The plot shows that for asymmetries less than 40 ppm, there is no obvious effect. For asymmetries greater than 40 ppm, the discrepancy of the different polarization corrections becomes increasingly significant as the sigma for the individually-corrected asymmetry becomes larger than the run-averaged corrected sigma. The discrepancy is greater for the greater variation in the polarization data set, and not discernible within the error bars for the 1% variation in the polarization data, which is the real data set. This plot is actually done with twice the number of hours of the experiment to achieve smaller error bars.

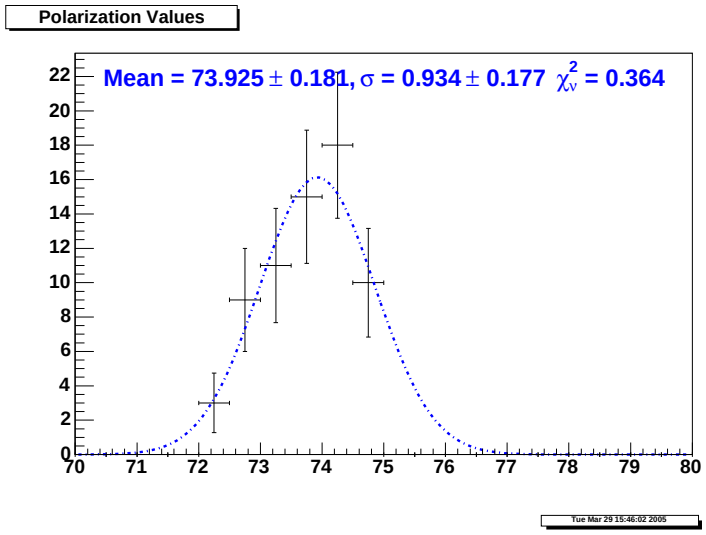


Figure 6: *A histogram of the polarization measurements.*

A second study was then performed, this one following the same basic procedure, but this time using a constant measured asymmetry of 120 ppm and varying the rate from 0.5 to 4.0 MHz. The simulation filled the Gaussian for each of the three polarization data sets and fitted the resulting distribution. This was also done for twice the number of hours of the actual experiment to increase the number of statistics. The results of this study are shown in Figure 5, which shows the sigma from the fit of the Gaussian of the run-averaged polarization-corrected asymmetry divided by the sigma from the fit of the individual measurement-corrected Gaussian versus the different rates, for each of the three polarization data sets. As before, the real polarization data set (the 1% variation) does not display much of a discrepancy with the increasing rates in this range, but the 5% and the 10% show an increasingly larger effect.

The study showed that there does not appear that there is any real discrepancy between the two correction methods for the asymmetries and rates in the range of the actual experiment. The simulation was repeated using asymmetrically varied polarization sets, and thus different mean values, but there was little difference from the results of the symmetrical case. To determine whether the polarization measurements are actually symmetrically varied, all nineteen average measurements were filled into a histogram and fitted with a Gaussian, shown in Figure 6. The fit is somewhat Gaussian, but the information to be gained from it is limited by the low statistics [11].

### Møller Systematic Error

The uncertainty of the polarization measurement has contributions from the foil polarization, target heating and warping, and various other errors in the set-up and tuning of the equipment. The contributions to the systematic error are summarized in Table 2. The systematic error uncertainties due to potential mis-tuning or misalignment of the various parts of the polarimeter have been well studied before, as have the contributions of the uncertainty of the beam position measurement, the corrections for the Levchuk effect (the motion of the atomic electrons in the iron target), and the contribution of multiple scattering [12], [13].

For the $G^0$ run, the Møller solenoid field was set to 3T instead of 4T, due to historical reasons. This field setting gave a target polarization of $0.08036 \pm 0.00015$, so there is a $+0.1\%$ correction to the beam polarization numbers, and a contribution of 0.19% to the uncertainty.[1] At 3T, $2^\circ$ of target warping yields an uncertainty of 0.37%. For the measurement current of 2 $\mu$A, and a beam spot size of 100 $\mu$m, the effect on the polarization of target heating from the beam on the iron foil is 0.2%, with a random uncertainty of 0.1%.

Leakage beam from the other halls gives a contribution of 0.2% fractional error on the polarization in the worst case scenario. The correction for the charge measurement is very small, at most $Q_+/Q_- \sim 1.008$, and usually smaller. The charge asymmetry is even smaller. The gain of the BCMs is nonlinear at the 0.2

[1] For a 4T field, the target foil polarization is $8.043 \pm 0.015\%$.

- 0.3% level, which is negligible for these measurements. Assuming the offset is uncertain at the 10 kHz level (0.25 counts/MHz versus 0.24), this leads to a 0.02% effect.

The level translators have 15 ns gates, as opposed to the 6 ns gate of the calorimeters. For a typical Møller run, the rates are $\sim$ 25 kHz, and so the effect on the Møller asymmetry of the electronic deadtime is 0.04%.

To be conservative, we have added two more sources of error: one for the high-current extrapolation, and another for accelerator ambiguities. There is no current dependence of the polarization measurement at the 1 % level up to 10 $\mu$A, verified by tests with the Møller raster in 2003, and there is no convincing argument for a change in beam polarization at higher currents. However, there have been no good measurements of the beam polarization in this current range. Tests with the Møller kicker in 2004 looked good at the 1 - 2% level at 40 $\mu$A, but the source was too unstable for a precise measurement. In the interest of being conservative, a 1% fractional uncertainty is assumed for the extrapolation from 2 $\mu$A to 40 $\mu$A. The 0.5% designated for accelerator ambiguities is meant to account for any laser spot moves, quantum efficiency changes, or other accelerator configuration changes that affected the polarization but were not recorded.

There is a global systematic shift of +0.3% up in polarization for all points (not yet applied to these points in this note) for the correction for the target polarization and target heating. The conservative number for the total systematic uncertainty, including the contributions from the high-current extrapolation and the accelerator ambiguitites, is 1.32%. The total sytematic uncertainty without the high-current extrapolation, but with the accelerator-ambiguity, is 0.86%, and without either of these errors, 0.70%. All these are fractional [14].

Table 2 summarizes these uncertainties and give the total, conservative effect on the polarization.

| Source | Uncertainty | Effect on A (%) |
|---|---|---|
| Beam position x | 0.5 mm | 0.15 |
| Beam position y | 0.5 mm | 0.03 |
| Beam angle x | 0.15 mr | 0.04 |
| Beam angle y | 0.15 mr | 0.04 |
| Current Q1 | 2 % | 0.10 |
| Current Q2 | 1 % | 0.07 |
| Position Q2 | 1 mm | 0.02 |
| Multiple Scattering | 10 % | 0.12 |
| Levchuk Effect | 10 % | 0.30 |
| Collimator Position | 0.5 mm | 0.06 |
| Target Temperature | 5° | 0.2 |
| Direction B-field | 2° | 0.06 |
| Value B-field | 5 % | 0.03 |
| Spin Polarization in Fe | 0.19% | 0.1 |
| Target Warping | 2° | 0.37 |
| Leakage | | 0.2 |
| High-Current | | 1.0 |
| Solenoid Monte-Carlo | | 0.1 |
| Electronic Deadtime | | 0.04 |
| Charge Measurement | | 0.02 |
| Monte Carlo Statistics | | 0.28 |
| Accelerator Ambiguities | | 0.5 |
| Total Corrections | | +0.3 |
| Total Uncertainty | | 1.32 |

Table 2: *Sources of error in the determination of the beam polarization (solenoid at 3T). The percentages are fractional.*

**Final Beam Polarization Results**

The final numbers for the polarization of the electron beam for the $G^0$ experiment are listed in Table 3. The values are shown for the appropriate time periods and data run number ranges that that polarization is valid for, and they cover the time from January to the end of the run in May. The justification for the division of the runs into these ranges is given in Appendix D. Figure 7 shows the absolute polarization versus date for the experiment, shown by IHWP state, with dotted lines to indicate the time periods of constant polarization. The fits for each time period are also shown on the plot. The error bars are statistical, except for the transverse numbers, which are quasi-statistical with some interpolation error folded in. Figure 8 is a plot of the absolute polarization versus date for both IHWP states, with a global fit for each half-wave plate state [14]. It is important to note that the Wien filter was not at a spin-dance verified setting for optimal longitudinal polarization before the spin dance on February 10th, when the Wien angle was changed from -9.5 to -12.64 degrees. After the change to four-pass beam on March 15th, the Wien angle was not changed to compensate for the additional pass through the accelerator until March 16th. The Wien angle was changed to +11.50 from -12.64, but this was not the optimal angle for longitudinal polarization and was not verified by a spin dance. After the transverse running and the March 26th spin dance, the Wien angle was again optimized at an angle of +2.5 degrees.

| Run Range | Polarization (%) | IHWP | Time Period | Comments |
|---|---|---|---|---|
| 18868-19238 | $74.03 \pm 0.46$ | in | 1/11 - 1/22 | |
| 18868-19238 | $73.16 \pm 0.50$ | out | 1/11 - 1/22 | |
| 19239-19571 | $74.57 \pm 0.21$ | in | 1/22 - 2/3 | |
| 19239-19571 | $74.49 \pm 0.30$ | out | 1/22 - 2/3 | |
| 19597-19774 | $72.05 \pm 0.43$ | in | 2/5 - 2/10 | |
| 19780-20055 | $73.02 \pm 0.21$ | in | 2/10 - 2/20 | |
| 19780-20055 | $72.57 \pm 0.20$ | out | 2/10 - 2/20 | |
| 20056-20576 | $73.29 \pm 0.19$ | in | 2/20 - 3/9 | |
| 20056-20576 | $73.45 \pm 0.18$ | out | 2/20 - 3/9 | |
| 20633-20743 | $74.46 \pm 0.42$ | in | 3/16 - 3/20 | |
| 20633-20743 | $73.84 \pm 0.31$ | out | 3/16 - 3/20 | |
| 20744-20790 | $73.49 \pm 0.36$ | in | 3/20 - 3/22 | |
| 20791-20900 | $74.18 \pm 0.74$ | in | 3/22 - 3/26 | Transverse |
| 20791-20900 | $74.45 \pm 0.74$ | out | 3/22 - 3/26 | Transverse |
| 20901-21222 | $74.19 \pm 0.18$ | in | 3/26 - 4/7 | |
| 20901-21222 | $74.46 \pm 0.19$ | out | 3/26 - 4/7 | |
| 21223-21347 | $73.79 \pm 0.30$ | in | 4/7 - 4/12 | |
| 21223-21347 | $74.12 \pm 0.36$ | out | 4/7 - 4/12 | |
| 21348-22003 | $74.27 \pm 0.21$ | in | 4/12 - 5/12 | |
| 21348-22003 | $73.72 \pm 0.16$ | out | 4/12 - 5/12 | |
| 22004-999999 | $74.67 \pm 0.29$ | in | 5/12 - end | |
| 22004-999999 | $74.75 \pm 0.27$ | out | 5/12 - end | |

Table 3: *The absolute polarization for the $G^0$ second-engineering and physics data runs. Error bars are statistical, except for the transverse numbers, which are quasi-statistical with some interpolation error folded in.*

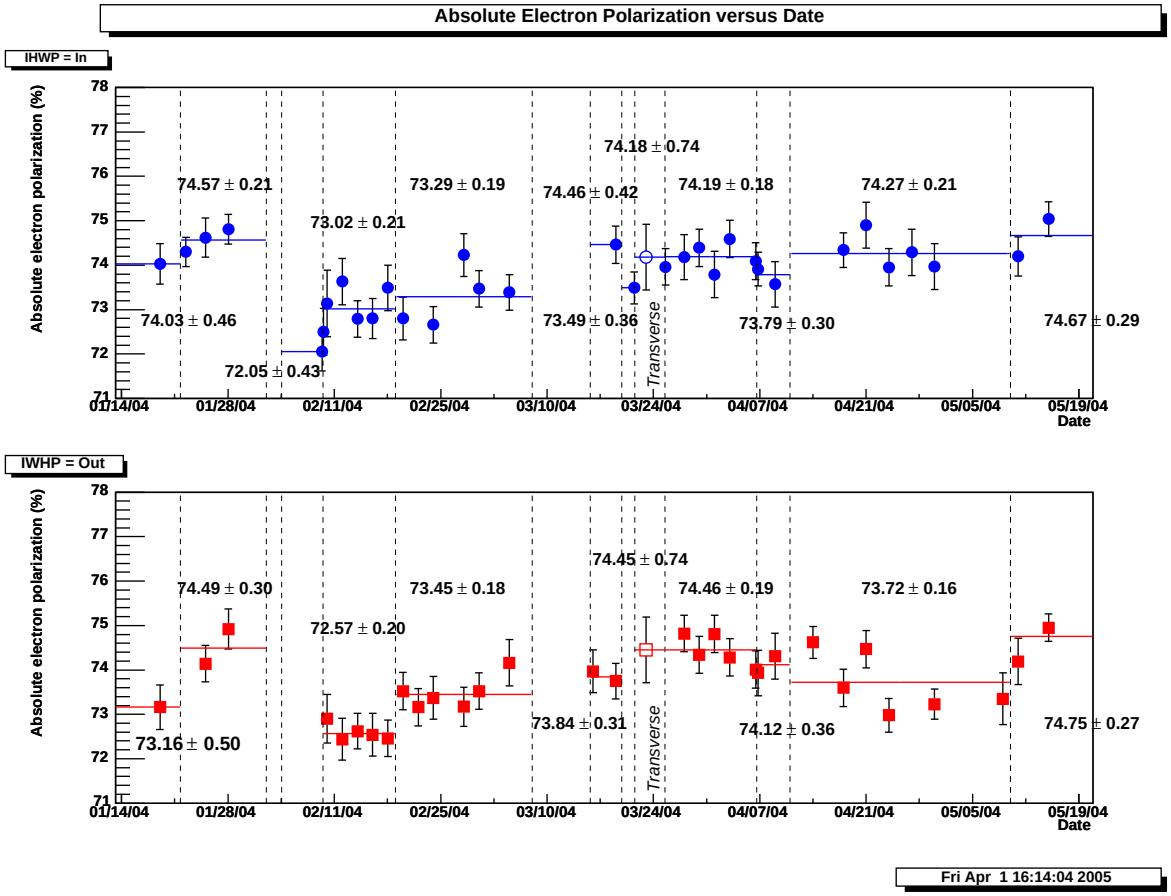


Figure 7: *The absolute polarization for the $G^0$ second-engineering and physics data runs, shown by IHWP state. Error bars are statistical, except for the transverse numbers, which are quasi-statistical with interpolation error folded in.*

I gratefully acknowledge all the help that Dave Gaskell has given to me while working on this project. He has helped to make this work fun and interesting. I also want to recognize the other members of the talented Møller group for their excellent work and logbook entries during the run: Dave Gaskell, Damon Spayde, and Tanja Horn. Without their well-written entries, many mysteries would remain unsolved.

For more information about the lovely Hall C Møller polarimeter, read Matthias Loppacher's Ph.D. thesis entitled *Møller Polarimetry for CEBAF Hall C* [7], or visit http://www.jlab.org/~moller/literature_moller.html.

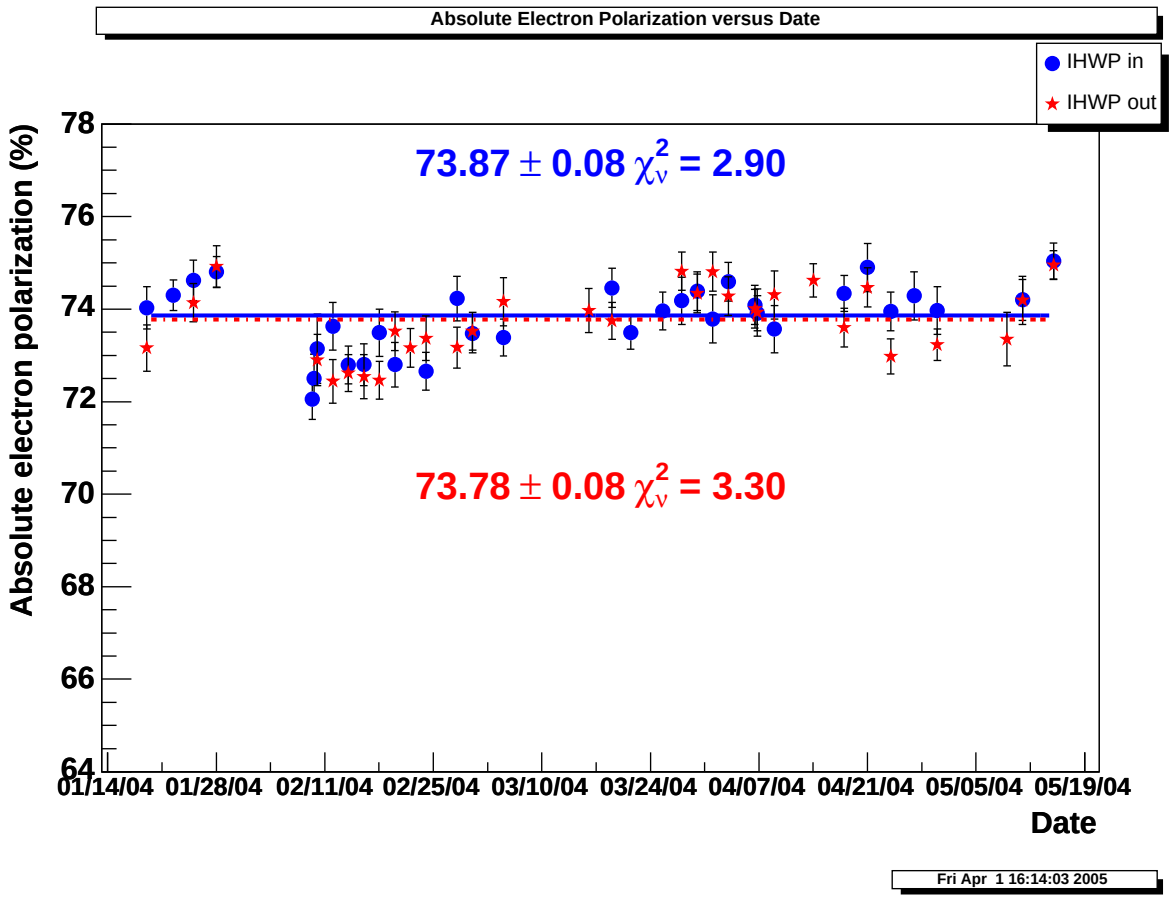


Figure 8: *The absolute polarization for the $G^0$ second-engineering and physics data runs, shown with a global fit by IHWP state. Error bars are statistical, except for the transverse numbers, which are quasi-statistical with interpolation error folded in.*

# A Polarization Measurements

The following tables contain listings of the polarization measurements made with the Møller polarimeter during the second engineering run and the forward-angle physics run of the $G^0$ experiment.

Leakage polarization measurements are included.

| Date | **Polarization (%)** | | Comment |
|---|---|---|---|
| | Half-Wave Plate IN | Half-Wave Plate OUT | |
| December 8, 2003 | —— | $+65.75 \pm 0.43$ | Hall B leakage, laser wavelength not optimized |
| December 9, 2003 | —— | $-71.71 \pm 0.45$ | After beam spot move 1/9 |
| December 13, 2003 | —— | $-72.08 \pm 0.11$ | |
| December 23, 2003 | $+70.82 \pm 0.45$ | —— | Spot move 12/21; needs leakage correction |
| December 24, 2003 | $+70.42 \pm 0.34$ | —— | With kicker; needs leakage correction |
| December 23-24, 2003 | $+72.80 \pm 0.34$ | —— | Combined good runs; leakage corrected |
| January 20, 2004 | $+74.03 \pm 0.46$ | $-73.16 \pm 0.50$ | Spot moves on 1/7 and 1/13 |
| January 20, 2004 | $-34.46 \pm 39.77$ | —— | Hall B leakage, $\sim$ 10nA |
| January 23, 2004 | $+74.30 \pm 0.33$ | —— | Spot move 1/22, before this measurement |
| January 26, 2004 | $+74.62 \pm 0.44$ | $-74.14 \pm 0.41$ | |
| January 26, 2004 | —— | $-39.31 \pm 77.03$ | Hall A and B leakage, $\sim$ 10nA |
| January 26, 2004 | —— | $+60.54 \pm 17.95$ | Hall A and B leakage, $\sim$ 15nA |
| January 29, 2004 | $+74.81 \pm 0.33$ | $-74.92 \pm 0.45$ | |

Table 4: *The measured beam polarization in December and January during the $G^0$ Experiment.*

| Date | **Polarization (%)** | | Comment |
|---|---|---|---|
| | Half-Wave Plate IN | Half-Wave Plate OUT | |
| February 10, 2004 | $+72.05 \pm 0.43$ | —— | Wien angle = -9.50 |
| February 10, 2004 | $+72.50 \pm 0.53$ | —— | Wien angle = -12.62 |
| February 11, 2004 | $+73.14 \pm 0.75$ | $-72.90 \pm 0.55$ | |
| February 13, 2004 | $+73.63 \pm 0.52$ | $-72.44 \pm 0.47$ | |
| February 13, 2004 | —— | $+55.35 \pm 11.83$ | Hall B leakage, $\sim$ 10nA (g0log 76516). |
| February 15, 2004 | $+73.79 \pm 0.42$ | $-72.64 \pm 0.40$ | |
| February 17, 2004 | $+72.80 \pm 0.45$ | $-72.54 \pm 0.48$ | |
| February 19, 2004 | $+73.49 \pm 0.51$ | $-72.46 \pm 0.41$ | |
| February 21, 2004 | $+72.80 \pm 0.48$ | $-73.52 \pm 0.42$ | |
| February 23, 2004 | —— | $-73.16 \pm 0.42$ | |
| February 25, 2004 | $+72.66 \pm 0.41$ | $-73.37 \pm 0.48$ | |
| February 29, 2004 | $+74.23 \pm 0.48$ | $-73.17 \pm 0.44$ | |
| March 2, 2004 | $+73.47 \pm 0.41$ | $-73.52 \pm 0.41$ | |
| March 6, 2004 | $+73.39 \pm 0.40$ | $-74.16 \pm 0.52$ | |
| March 17, 2004 | —— | $+73.97 \pm 0.48$ | Sign change due to pass/energy change March 8. |
| March 20, 2004 | $-74.46 \pm 0.42$ | $+73.75 \pm 0.40$ | |
| March 22, 2004 | $-72.79 \pm 0.51$ | —— | Prior to spin dance, Wien at +11.50 |
| March 22, 2004 | $-0.01 \pm 0.55$ | —— | Transverse running, Wien at -85.23 |
| March 26, 2004 | $-3.67 \pm 0.52$ | —— | Transverse running, Wien at -85.23 |
| March 26, 2004 | $-73.96 \pm 0.41$ | —— | Resume longitudinal running, Wien at +2.50 |
| March 29, 2004 | $-74.18 \pm 0.51$ | $+74.82 \pm 0.41$ | |
| March 31, 2004 | $-74.39 \pm 0.42$ | $+73.38 \pm 0.51$ | |

Table 5: *The measured beam polarization in February and March during the $G^0$ Experiment.*

| Date | **Polarization (%)** | | Comment |
|---|---|---|---|
| | Half-Wave Plate IN | Half-Wave Plate OUT | |
| April 2, 2004 | $-73.79 \pm 0.52$ | $+74.81 \pm 0.42$ | |
| April 4, 2004 | $-74.59 \pm 0.42$ | $+74.28 \pm 0.42$ | |
| April 7, 2004 | $-74.09 \pm 0.42$ | $+74.01 \pm 0.42$ | |
| April 7, 2004 | $-73.91 \pm 0.38$ | $+73.93 \pm 0.51$ | Seven hours later, after spot change. |
| April 10, 2004 | $-73.57 \pm 0.51$ | $+74.31 \pm 0.52$ | |
| April 15, 2004 | —— | $+74.83 \pm 0.52$ | Hall A at 100$\mu$A. |
| April 15, 2004 | —— | $+74.40 \pm 0.52$ | Hall A at 100$\mu$A, Hall B at 25 nA. |
| April 15, 2004 | —— | $-35.37 \pm 5.53$ | Hall A and B leakage (g0log 82207). |
| April 19, 2004 | $-74.34 \pm 0.39$ | $+73.60 \pm 0.42$ | |
| April 22, 2004 | $-74.90 \pm 0.52$ | $+74.47 \pm 0.42$ | |
| April 25, 2004 | $-73.95 \pm 0.42$ | $+72.98 \pm 0.38$ | |
| April 25, 2004 | $+55.97 \pm 4.76$ | —— | Hall A and B leakage, $\sim 50\mu$A, C slit wide open |
| April 28, 2004 | $-73.93 \pm 0.42$ | —— | 10$\mu$A attenuator setting |
| April 28, 2004 | $-74.29 \pm 0.52$ | —— | 40$\mu$A attenuator setting |
| May 1, 2004 | $-73.97 \pm 0.52$ | $+73.23 \pm 0.34$ | |
| May 1, 2004 | —— | $-50 \pm 5$ | Leakage measurement, g0log 83734 |
| May 10, 2004 | —— | $+73.35 \pm 0.58$ | |
| May 12, 2004 | $-74.20 \pm 0.44$ | $+74.19 \pm 0.52$ | |
| May 16, 2004 | $-74.95 \pm 0.40$ | $+74.90 \pm 0.31$ | |

Table 6: *The measured beam polarization in April and May during the $G^0$ Experiment.*

## B Leakage Polarization Measurements

The following table contains a listing of the leakage polarization measurements made with the Møller polarimeter during the second engineering run and the forward-angle physics run of the $G^0$ experiment.

| **Date** | **Polarization (%)** | | **Comment** |
|---|---|---|---|
| | Half-Wave Plate IN | Half-Wave Plate OUT | |
| December 24, 2004 | *Current Measurement Only* | *Current Measurement Only* | Hall B leakage, Current Measurement,$\sim$ 30nA, (g0log 72512), with kicker. |
| January 20, 2004 | $-34.46 \pm 39.77$ | —— | Hall B leakage, $\sim$ 10nA (extrapolated), (g0log 74610), Hall C slit at 2$\mu$A position. |
| January 26, 2004 | —— | $-39.31 \pm 77.03$ | Hall A and B leakage, $\sim$ 10nA, (g0log 74610), Hall C slit at 2$\mu$A position. |
| January 26, 2004 | —— | $+60.54 \pm 17.95$ | Hall A and B leakage, $\sim$ 15nA, (g0log 74610), Hall C slit at 40$\mu$A position. |
| February 13, 2004 | —— | $+55.35 \pm 11.83$ | Hall B leakage, $\sim$ 10nA, (g0log 76516). |
| April 15, 2004 | —— | $-35.37 \pm 5.53$ | Hall A and B leakage, (g0log 82207). |
| April 25, 2004 | $+55.97 \pm 4.76$ | —— | Hall A and B leakage, $\sim$ 50nA, C slit wide open. |
| May 1, 2004 | —— | $-50 \pm 5$ | Using attenuator, slit wide open g0log 83734 |

Table 7: *The measured leakage beam polarization from Halls A and B throughout the $G^0$ Experiment.*

# C Spin Dance Polarization Measurements

For the February 10, 2004 spin dance[2], the IHWP was in. Table 8 lists the polarization measurements at each Wien angle setting. Figure 9 shows a fit to the measured data of the form $P_{meas} = P_e \cos(\eta_{Wien} + \phi)$, where $P_{meas}$ is the measured beam polarization at each Wien angle setting, $\eta_{Wien}$ is the Wien angle, and $\phi$ is the relative phase. After the spin dance, the Wien was set to -12.62 degrees to maximize the longitudinal polarization and minimize any transverse components of the beam [15], [8].

| Wien Angle (degrees) | Polarization (%) |
|---|---|
| -9.50 | $+72.05 \pm 0.43$ |
| -50.21 | $+58.84 \pm 0.52$ |
| -90.24 | $+15.19 \pm 0.58$ |
| 35.20 | $+49.45 \pm 0.50$ |
| 80.23 | $-2.98 \pm 0.47$ |
| -12.62 | $+72.50 \pm 0.53$ |

Table 8: *The measured beam polarization during the Spin Dance on February 10, 2004. The IHWP state was IN.*

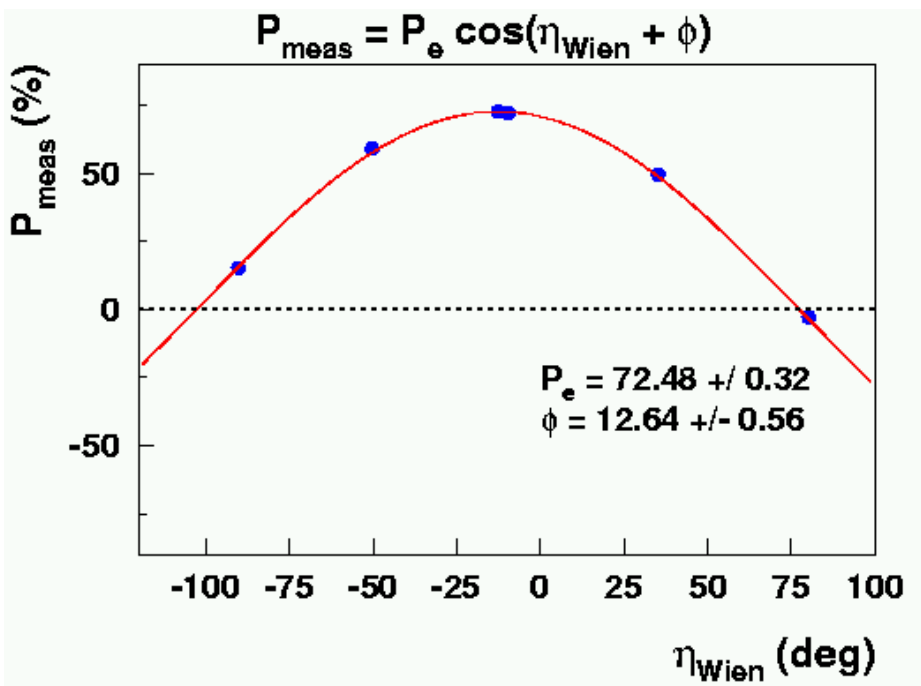


Figure 9: *A plot of the measured polarization versus Wien angle, with the fit to the data of the form* $P_{meas} = P_e \cos(\eta_{Wien} + \phi)$.

[2] A note on the terminology here: I have retained the terminology that the Møller group used during the run and in the $G^0$ electronic logbook, that is that the three spin-dances are called the spin dance, the mini-spin dance, and the micro-spin dance, in that order. I have kept the usage we recorded in the logbook, but there is no real reason that they should not all just be referred to as spin dances.

For the March 22, 2004 mini-spin dance, the IHWP was in. The measurements gave an optimal longitudinal Wien setting of +3.69 degrees, and the two zero-crossings for the optimal transverse polarization Wien settings: -84.99 degrees (small Wien angle) and +93.90 degrees (large Wien angle) [16], [17]. The Wien angle was set to -85.23 degrees for the transverse running. Figure 10 shows a plot of the negative of the polarization ($-P_{meas}$) versus the Wien angle setting with a fit of the form $P_{meas} = P_e \cos(\eta_{Wien} + \phi)$, where $\eta_{Wien}$ is the Wien angle and $\phi$ is the relative phase. Note that the optimal Wien angle for longitudinal polarization changed significantly between the February spin dance and this one, as expected due to the accelerator energy-per-pass configuration change on March 8th.

| **Wien Angle (degrees)** | **Polarization (%)** | **Comment** |
|---|---|---|
| +11.50 | $-72.79 \pm 0.51$ | |
| +56.21 | $-46.57 \pm 0.50$ | |
| +101.26 | $+9.76 \pm 0.49$ | |
| -34.20 | $-61.05 \pm 0.51$ | |
| -80.23 | $-5.62 \pm 0.51$ | |
| -86.24 | $+1.05 \pm 0.58$ | |
| -92.25 | $+9.15 \pm 0.49$ | |
| -34.40 | $-61.38 \pm 0.72$ | |
| -40.20 | $-56.02 \pm 0.72$ | |
| -85.23 | $-0.01 \pm 0.55$ | Transverse polarization setting |

Table 9: *The measured beam polarization during the Mini-Spin Dance on March 22, 2004. The IHWP state was IN.*

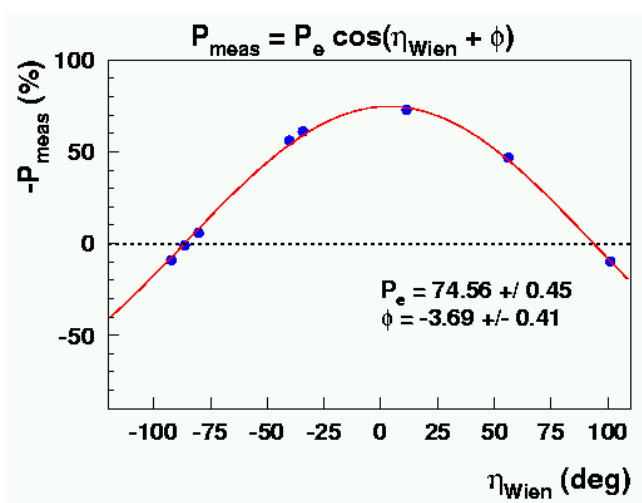


Figure 10: *A fit of the form $P_{meas} = P_e \cos(\eta_{Wien} + \phi)$ to the polarization data from the March 22 mini-spin dance.*

For the March 26, 2004 micro-spin dance, the IHWP was in. Table 10 lists the polarization measurements at each Wien angle setting of the spin dance. Figure 11 shows a fit to the measured data of the form $P_{meas} = P_e \cos(\eta_{Wien} + \phi)$ to the electron polarization from the Møller data versus the Wien angle, where $P_{meas}$ is the measured beam polarization at each Wien angle setting, $\eta_{Wien}$ is the Wien angle, and $\phi$ is the relative phase. The spin dance gave a zero crossing at $-87.98 \pm 0.71$ degrees for the transverse running, whereas in the previous spin-dance the best fit crossing was $-84.99 \pm 0.68$ degrees. It is not understood why this drift in the zero-point crossing occurred. After the spin dance, the Wien was changed to +2.5 degrees to maximize the longitudinal polarization and minimize any transverse components of the beam [18], [19]. Note that the negative of the polarization ($-P_{meas}$) is plotted for ease of viewing.

There was a new high voltage setting on the shower counters for all of these measurements.

| **Wien Angle (degrees)** | **Polarization (%)** | **Comment** |
|---|---|---|
| -85.23 | $-3.67 \pm 0.52$ | Beam off for one hour before rest of data set. |
| -90.24 | $+3.14 \pm 0.50$ | New HV setting for all measurements. |
| -20.20 | $-68.32 \pm 0.51$ | |
| +25.20 | $-68.69 \pm 0.42$ | |
| +2.50 | $-73.96 \pm 0.41$ | |

Table 10: *The measured beam polarization during the Micro-Spin Dance on March 26, 2004. The IHWP state was IN.*

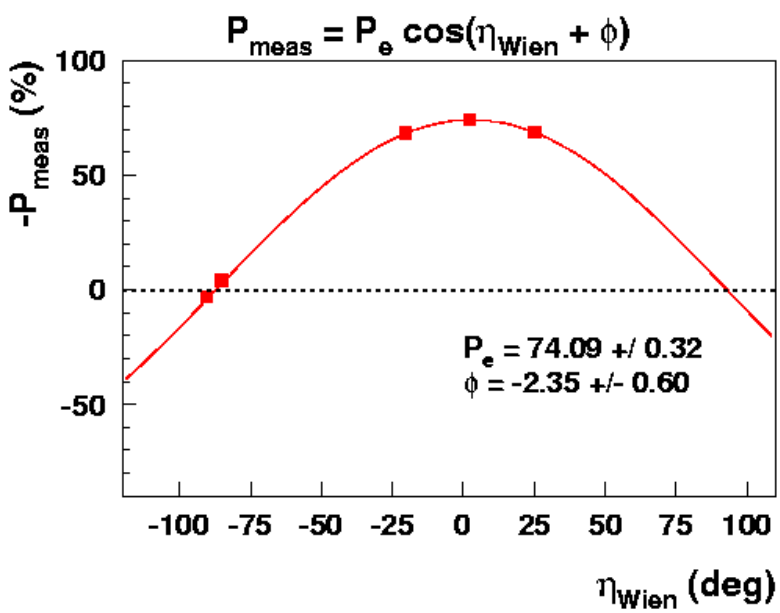


Figure 11: *A plot of the measured polarization versus Wien angle, with the fit to the data of the form* $P_{meas} = P_e \cos(\eta_{Wien} + \phi)$.

# D Justification of Polarization Time Periods

This appendix contains the events that defined the choice of the time periods that each polarization measurement applies to. Each time period not only contains the events that defined the start and end of each time period, but also other events that may have had some slight impact upon the beam polarization.

For the period in early January before physics data-taking:

| | |
|---|---|
| 1/6/04 | Spot at x/y = 1270, 1140; polog 1188329 |
| 1/9/04 | Stepper motor problems; Spot shift due to this? polog 1189053 |
| 1/11/04 | Spot at x/y = 1280,1140; polog 1189276 |

For the period starting 1/13/04, ending 1/23/04 1-9 1270,1140

| | |
|---|---|
| 1/11/04 | Spot at x/y = 1280,1140; polog 1189276 at 21:28 |
| 1/20/04 | New Spot planned (x/y=1280,1140 to 1360,1160); Polog 1191096 |
| 1/22/04 | Spot moved (x/y = 1300,1140) No polog entry about when. |
| | Moved between 15:02 (polog 1191629) and 19:52 (polog 1191704) |
| | We are assuming that it moved during downtime that lasted until 16:30 (g0log 74146) |

For the period starting 1/23/04, ending 2/3/04

| | |
|---|---|
| 1/22/04 | Spot moved (x/y = 1300,1140) No polog entry about when. |
| | Moved between 15:02 (polog 1191629) and 19:52 (1191704) |
| | We are assuming that it moved during downtime that lasted until 16:30 (g0log 74146) |
| 1/23/04 | Kaz does a bunch of PZT stuff and changes laser phase, also changes quads at 20:04; g0log 74237 |
| 1/27/04 | Kaz changes the quads at midnight (00:12); g0log 74572, polog 1192506 |
| 2/3/04 | Machine downtime, maintenance period begins at 8:00am; g0log 75271 |
| 2/3/04 | Injector work - QPD re-installed, laser spots moved; polog 1193878, |
| | polog 1193896 (new spot location 1280,1120) |
| | Kaz calibrates QPD in polog entry 1193881 |

For the period starting 2/5/04, ending 2/10/05

| | |
|---|---|
| 2/5/04 | Machine starts up on 2/5/04 with new spot location at 1280,1120 |
| | (from old spot 1300,1140); polog 1193878, 1193896, 1194431 |
| | Beam restored after maintenance (sort of) at 21:20; g0log 75384, 75410 |
| 2/10/04 | Measurement at old Wien of -9.50 degrees. |
| | Spin Dance, new Wien angle at -12.62 degrees, spot at 1280,1120 |
| | g0log 76002; polog 1195295,1195301,1195312 |

For period starting 2/10/04, ending 2/20/04

| | |
|---|---|
| 2/10/04 | Spin Dance, new Wien angle at -12.62 degrees, spot at 1280,1120 |
| | g0log 76002; polog 1195295,1195301,1195312 |
| 2/10/04 | Kaz does helicity magnet and IA/PZT tests at 15:38; g0log 76011, polog 1195338 |
| 2/10/04 | "Connectorization" in injector at 12:50, g0log 76001 |
| 2/19/04 | Kaz changes PITA stuff 2:10am, g0log 77031 |
| 2/20/04 | PZT system failure and repair at 15:05? polog 1196944 |

For the period starting 2/20/04, ending 3/9/04

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| 2/20/04 | PZT system failure and repair at 15:05? 1196944 |
| 3/8/04 | Maintenance period at 8:00am, g0log 79006 |

For the period starting 3/16/04, ending on 3/20/04

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| 3/15/04 | Beam restored after pass/energy change (4-pass) at 16:00 |
| 3/16/04 | Wien changed to +11.496 (from -12.62) at 15:32, g0log 79364, 79370<br>* Not optimized by spin dance! *<br>* Also, runs before this point (20589-20632) have a dubious polarization!<br>No Moller measurements for the runs (20589-20632)! * |
| 3/20/04 | Kaz changes PITAs at 19:38, g0log 79787 |

For the period starting 3/20/04, ending on 3/22/04 with transverse running

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| 3/20/04 | Wien at +11.50 for this period. |
| 3/20/04 | Kaz changes PITAs at 19:38 g0log 79787 |
| 3/22/04 | Spin dance for transverse running (g0log 79972),<br>Wien changed to -85.23 degrees<br>Kaz changes PITAs (g0log 80014) |

For period starting 3/22/04, ending on 3/26/04, transverse running

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|---|---|
| 3/22/04 | spin dance for transverse running; g0log 79980,79983<br>Wien now at -85.23 degrees, g0log 79972 at 13:04 |
| 3/22/04 | Kaz changes PITA at 22:16, g0log 80014 |
| 3/26/04 | End of transverse run, spin-dance at noon; g0log 80445, 80448<br>Wien now at +2.5 degrees. |

For the period starting 3/26/04 after transverse running, ending on 4/7/04

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| 3/26/04 | After transverse spin-dance, 12:30pm; g0log 80445, 80448<br>Wien now at +2.5 degrees. |
| 4/7/04 | Ends at spot move on 4/7/04 at 16:34; polog 1206943,1205059 and<br>g0log 81727 and 81690 |

For the period starting 4/7/04 after spot move to 4/12/04

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| 4/7/04 | Spot move to (1280,1050) from (1280,1120) at 16:34; polog 1205059 and 1206943,<br>g0log 81727 and 81690 |
| 4/12/04 | Spot moves itself back to (1280,1120) at 5:17pm; polog 1206943 |

For the period starting 4/12/04, ending 5/12/04

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| 4/12/04 | Spot moves itself back to (1280,1120) at 5:17pm; polog 1206943 |
| 4/12/04 | Accelerator down for maintenance and CD0 tours at 7:00am, g0log 82114 |
| 4/15/04 | Beam restored to hall... Kaz changes PZT, polog 1207009, g0log 82190 |
| 5/12/04 | At 2:37 am, Kaz changes PZT voltages again; g0log 84751, 84781 |

For the period starting 5/12/04 to end of run

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| 5/12/04 | At 2:37 am , Kaz changes PZT voltages again; g0log 84751, 84781 |
| 5/17/04 | End of Run 7:08am; g0log 85383 - last run 22181 |

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