Overview on Systematic Studies of the HERMES Longitudinal Polarimeter

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1 Introduction

This report gives an overview on the most significant systematic studies performed on the HERMES Longitudinal Polarimeter (LPOL) during the period winter 2003-spring 2004. We have investigated some possible systematic dependences of the measured polarization from the LPOL, which is in disagreement (7%) with the Transverse Polarimeter (TPOL) measurements, observed in Spring 2003 data.

This study refers to data collected by using the crystal calorimeter. No dependence of the measurements on the laser energy, on the "Table Offset", on the position of the scattered Compton cone on the calorimeter, and on the noise induction from the laser high voltage was found. Also, no false asymmetry introduced by the hardware was observed.

2 Physics Overview and Apparatus Setup

At HERMES, the polarization measurement of the positron beam is performed by scattering a laser beam off the positrons. The back scattered Compton photons are thus detected by a crystal calorimeter 54 m downstream of the interaction point (IP). In the following, a brief overview of the physics involved and of the apparatus is given. For a detailed description the reader is referred to [1].

In Fig. 1 the kinematic of the scattering process is shown.

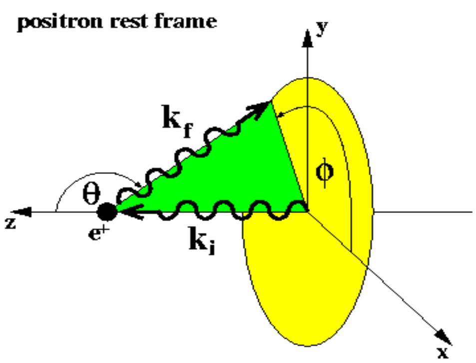

Figure 1: Kinematic of the laser scattering with the positron beam, as viewed in the positron rest frame.

The differential angular cross section for scattering polarized photons off polarized positrons is given by:

$$\frac{d\sigma}{d\Omega}(\vec{S},\vec{P}) = \frac{r_0 k_f^2}{2m_e k_i^2}(\Sigma_0 + \Sigma_1(S_1) + \Sigma_2(S_3,\vec{P})) \ , \tag{1}$$

with the photon (positron) $\vec{S}$ ($\vec{P}$) polarization, the classical electron radius r_0, the initial (final) photon momentum k_i (k_f), the electron mass m_e, the unpolarized term Σ_0, and the polarized parts $\Sigma_1(S_1)$ and $\Sigma_2(S_3,\vec{P})$. In particular,

S_3 corresponds to the circular polarization of the photon, and for perfectly circularly polarized light $S_1 = S_2 = 0$.

The longitudinal polarimeter LPOL exploits the dependence of the cross section on the energy E_γ of the scattered photon, by measuring the asymmetry of the energy deposition integral in the calorimeter for left (I^-) and right (I^+) circular photon polarization while having the positron beam longitudinal polarized.

In this case it is $P_x = P_y = 0$, $\Sigma_1 = 0$, and :

$$P_z = \frac{1}{A\bar{S}_3} \cdot \frac{I^+ - I^-}{I^+ + I^-} \ , \tag{2}$$

with the averaged circular light $\bar{S}_3 = \frac{1}{2}(\mid S_3^+ \mid + \mid S_3^- \mid)$ measured with both the analyzer $AB1$ in the laser room, and with the analyzer $AB2$ in the HERA tunnel after the interaction point, Fig. 2, and the *Analyzing Power A* calculated by using QED, based on calorimeter test beam calibrations.

The energy deposition integral is measured by operating the HERMES polarimeter in the so-called *multi-photon mode*, that is by detecting many back scattered Compton photons in one collision between the laser and the positron bunches. This mode allows a better separation of the ADC spectra with left and right circular laser polarization, respectively, as shown in the example of Fig. 3.

In order to evaluate the reliability of the LPOL polarization measurement, continuously systematic studies have been done. The more significant results are reported in the following sections, showing that no particular systematic effects in the LPOL operational mode affect the polarization measurement.

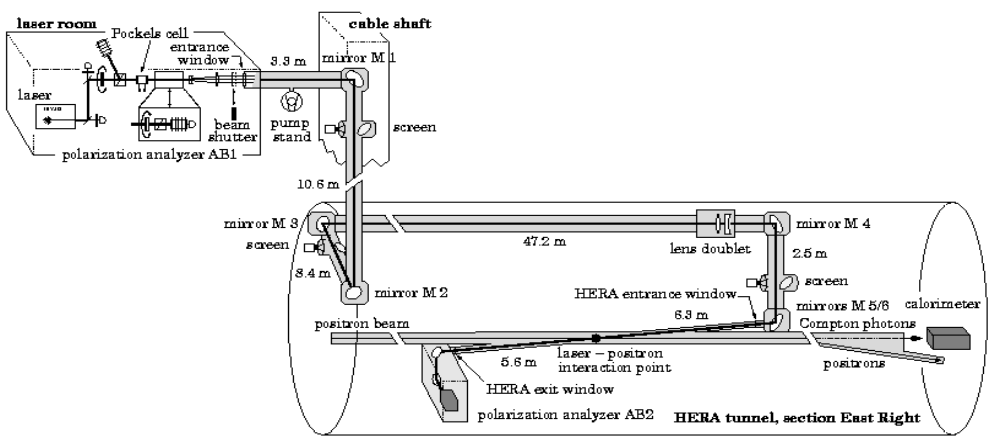

Figure 2: Global view of the experimental apparatus setup of the HERMES longitudinal polarimeter.

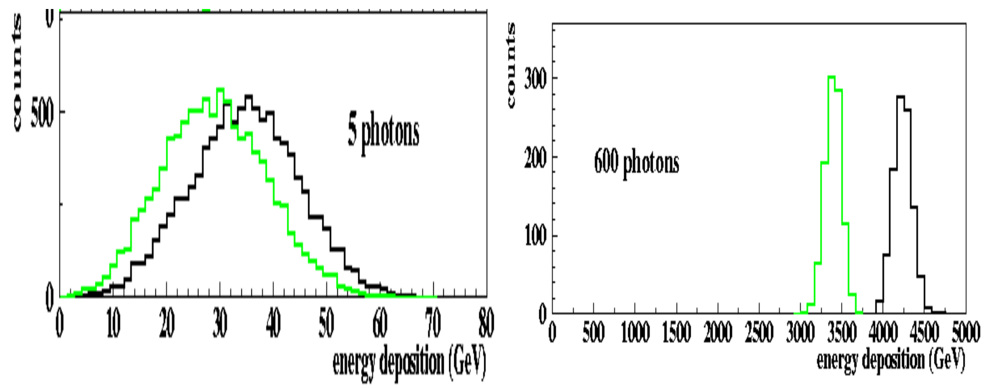

Figure 3: Model calculations for ADC spectra by laser firing 5 photons (left panel) and 600 photons (right panel). The spectra are shown for realistic conditions: $S_3P_3 = -0.5$ (black line) and $S_3P_3 = +0.5$ (green line).

3 Dependence on the Energy Deposition

The accuracy of polarization measurement strongly depends on the linearity of the crystal calorimeter. During a fill the positron current decreases and therefore also the energy delivered to the calorimeter decreases.

To monitor whether any non-linearity of the calorimeter affects the polarization, measurements are regularly taken delivering different amount of energy to the detector by changing the laser energy. The results of two measurements taken on Dec.2003 are shown in Fig. 4, where for each plot the upper panel shows the laser energy versus time. The behavior of the ratio of the polarization values taken with the longitudinal and transverse polarimeters (LPOL/TPOL) is shown in the bottom panel of the plots. While during these two measurements the beam conditions were not completely stable, no obvious luminosity dependency was found.

A polarization measurement with stable beam was taken on January 31^{st} by decreasing the laser energy from the nominal value of 200 mJ down to 100 mJ in steps of 25 mJ. The result of this test is shown in Fig. 5, confirming no energy deposition dependence of the polarization measurement.

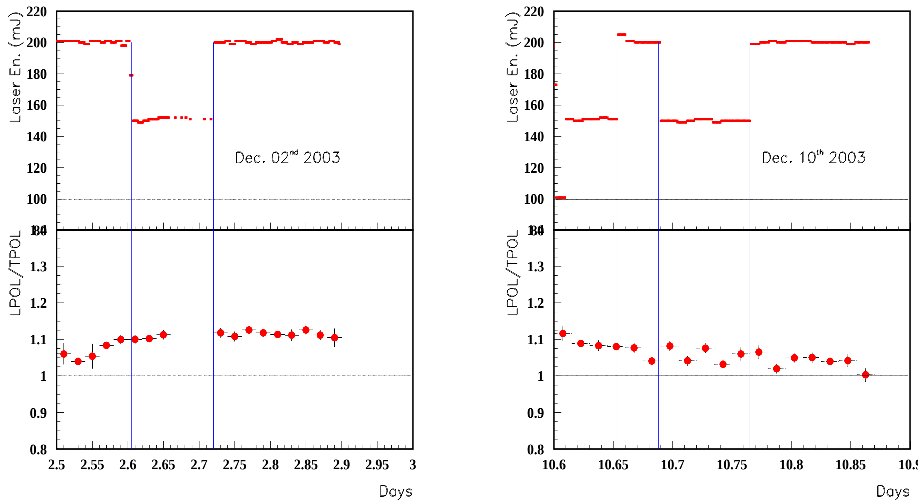

Figure 4: Polarization measurements taken on Dec. 2003 suggest that no linearity effects affect the crystal calorimeter response.

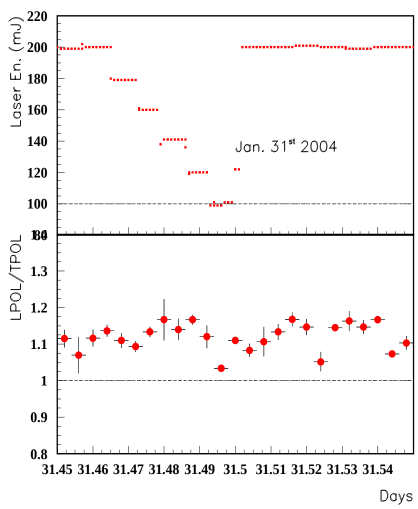

Figure 5: During stable conditions, polarization measurements were taken while changing the laser energy. The results show no sizable dependence of the polarization measurement on the deposited energy.

4 Sensitivity to the Table Offset

The polarization measurement may sizably depend on an important spatial variable, the Table Offset. This quantity refers to the displacement of the crystal calorimeter with respect to the center of the exit window where the Compton photons leave the beam pipe. The autopilot of the COP program always centers the scattered Compton cone on the calorimeter, and hence moves the calorimeter with respect to the exit window.

The optimal condition is when Compton photons are centered at the exit window. That can be achieved by positioning the e^+ beam or by adjusting the laser path. This can be understood by considering that the orientation of the Compton cone depends on the orientation of positrons and laser at the *IP*. Fig. 6 shows the geometry (not in scale) of Compton photons scattered from the *IP* which leave the beam pipe through the exit window and hit the calorimeter.

In extreme conditions, when Compton photons exit the pipe near the window frame, as shown in the insert of Fig. 6, the polarization measurement can be affected. The circular exit window has a radius of 17 mm while the dimensions of the elliptical Compton cone are $\sigma_x = 3.8$ mm and $\sigma_y = 1.1$ mm. Therefore, we can expect that for very large table offsets, the tail of the Compton cone may interact with the window frame affecting the measured positron beam polarization.

On February 4^{th}, a systematic study has been performed during stable beam condition. The mirror 4 was rotated in order to change the position of Compton photons at the exit window. The results of this analysis are shown in Fig. 7, and clearly indicate that for table offsets up to $\approx$ 7 mm no change of the LPOL/TPOL ratio is observed.

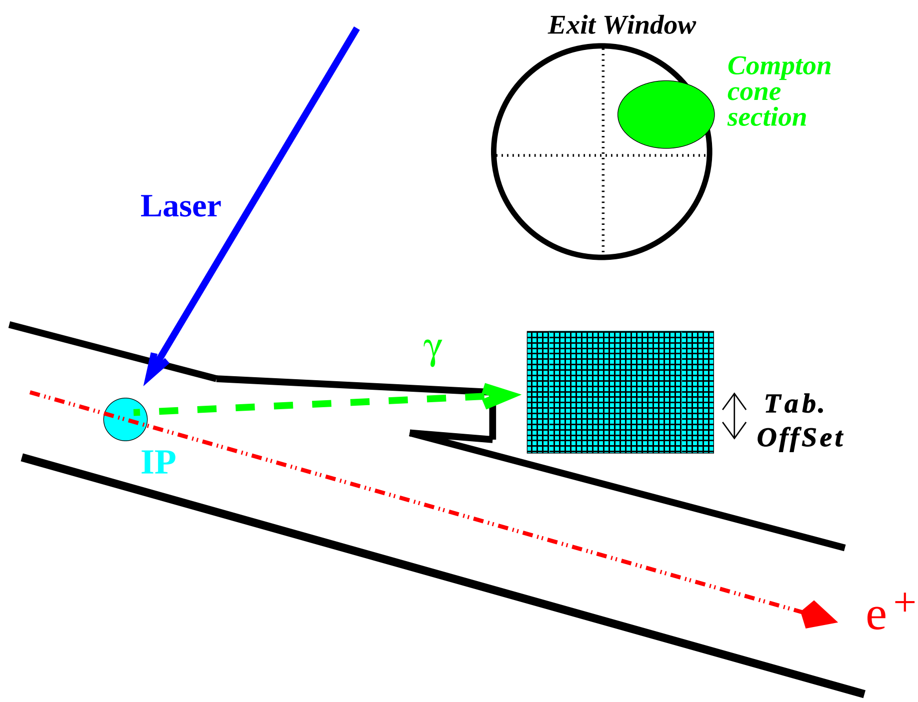

Figure 6: Qualitative picture showing the Compton photons scattered from the *IP* which exit the beam pipe through the exit window and hit the calorimeter.

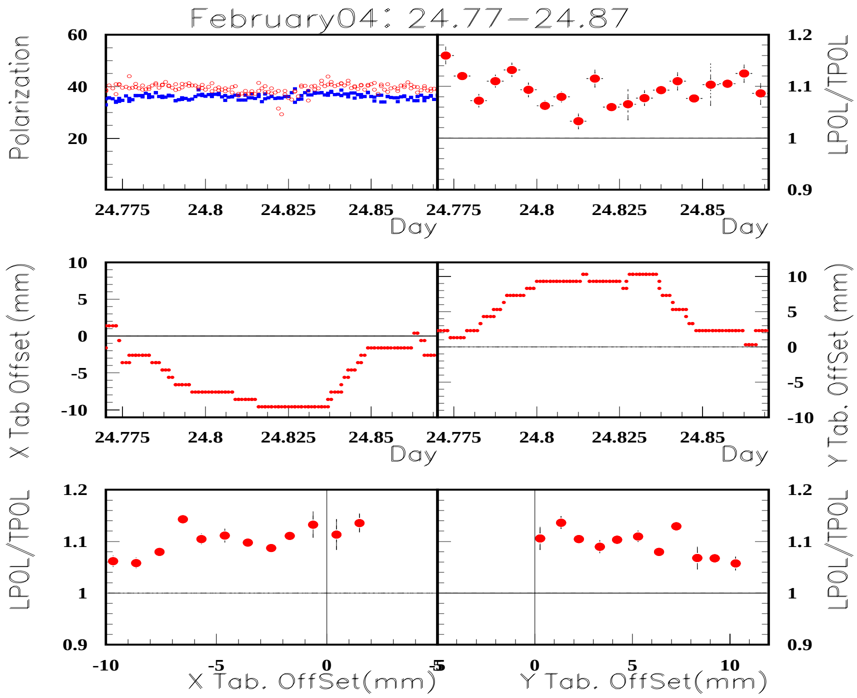

Figure 7: The beam polarization, red (black) points for LPOL (TPOL), and the ratio LPOL/TPOL are monitored versus time, upper panels. For the same period, x and y coordinates of the Table Offset are shown on the middle panels. The correlation of LPOL/TPOL with Table Offset is shown in the bottom panels. No systematic dependence on this quantity up to $\approx \pm 7\ mm$ is found.

Effects on the LPOL/TPOL show up for larger values only, which are far from the nominal working conditions (up to $\pm 2\ mm$), concluding that the polarization measurement is not affected by any calorimeter table offset observed within normal working conditions.

5 Spatial x-y Scanning of the Calorimeter

During a fill the positron beam and slope can drift, resulting in a Compton cone not properly centered in the calorimeter. Even though during normal LPOL operation Compton photons are centered in the calorimeter within 1 mm, it is crucial to verify how much an offset of Compton photons may affect the polarization measurement.

On April 9^{th}, during stable conditions with polarization $\approx 40\%$ and positron current $\approx 20 - 25$ mA, the calorimeter table has been moved along the horizontal direction. Only 3 mm separate the beam pipe from the calorimeter table, resulting in a limited horizontal scan ranging in ± 2 mm.

The tilting of the beam with respect to the HERA tunnel, resulted in a smaller shift of the Compton photons x coordinate as compared to the table movement, and in a displacement of the Compton beam also along the y-direction, Fig. 8. While considering the TPOL measurement as the reference polarization value, during the x-table scanning the LPOL polarization measurement was found to be stable within 1%, Fig. 9. In the plot, the results of fitting the data by a straight line are reported.

On April 27^{th}-28^{th} two table scans in the y-direction (vertical scan) have been performed, resulting in the Compton cone hitting the calorimeter at negative and positive y-values, respectively. Only the limited vertical scan within ± 3 mm was performed, because larger values approach the plateau of the η-y transformation typical of the used crystal calorimeter [2], resulting in a bad determination of the Compton photons coordinates. Also, at larger values low energy is delivered in some of the PMTs of the calorimeter affecting the position measurement itself. The results of the above measurements are reported in Fig. 10, closed and open circles respectively, showing a stable LPOL measurement within 2%.

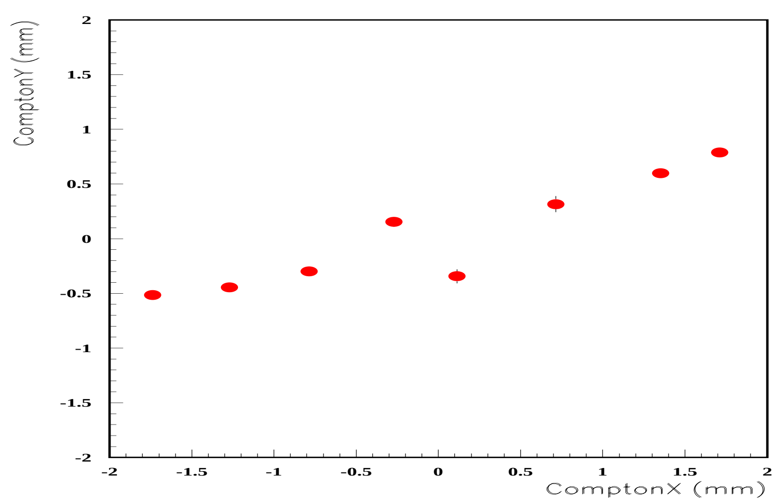

Figure 8: Due to the tiltness of the positron beam on respect to the HERA tunnel, a calorimeter table scan in the in x-scanning results also in a displacing of the the Compton beam also along the y-direction.

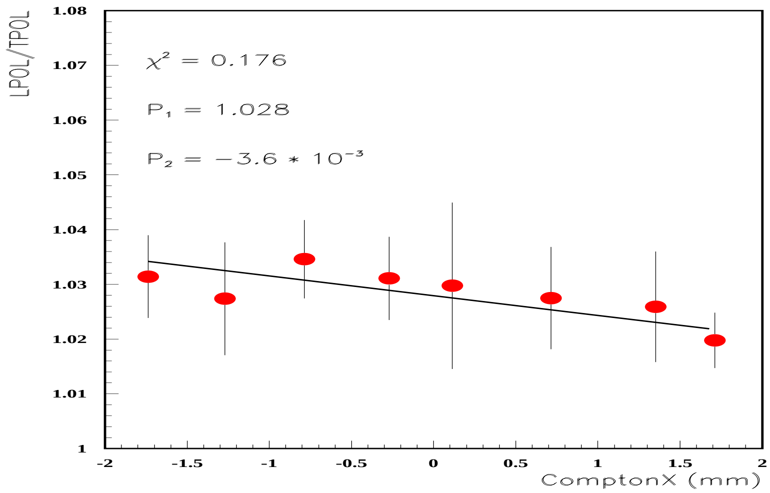

Figure 9: While considering the TPOL measurement as the reference polarization value, during the x- table scanning the LPOL polarization measurement was found to be stable within 1%.

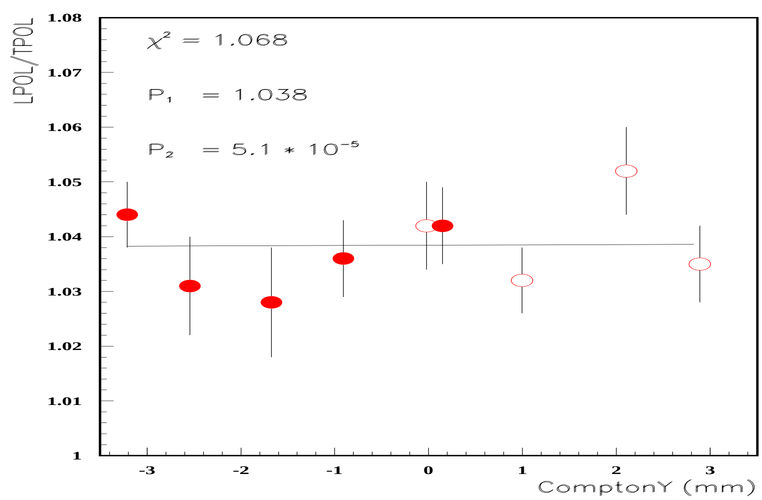

Figure 10: While considering the TPOL measurement as the reference polarization value, during the y- table scanning the LPOL polarization measurement was found to be stable within 2%.

6 Noise Introduced by Laser High Voltage

The firing of the laser causes electromagnetic noise that couples into the PIN diodes and the signal cables in the laser hut, which propagate into the electronic trailer (ET) thus affecting finally all the ADC values. The subtraction of this noise is performed by measuring the signal with laser firing on empty bunches.

To quantify the influence of this noise on the polarization measurement, on March 19^{th} data have been analyzed with and without this correction. This study has been performed by comparing the data when firing on filled bunches with the data when firing on all bunch positions, respectively. During the data taking the beam conditions were stable, with $\approx 30\%$ of polarization.

The results of this study are reported in Fig. 11 showing that the noise from laser firing does not affect the polarization measurement.

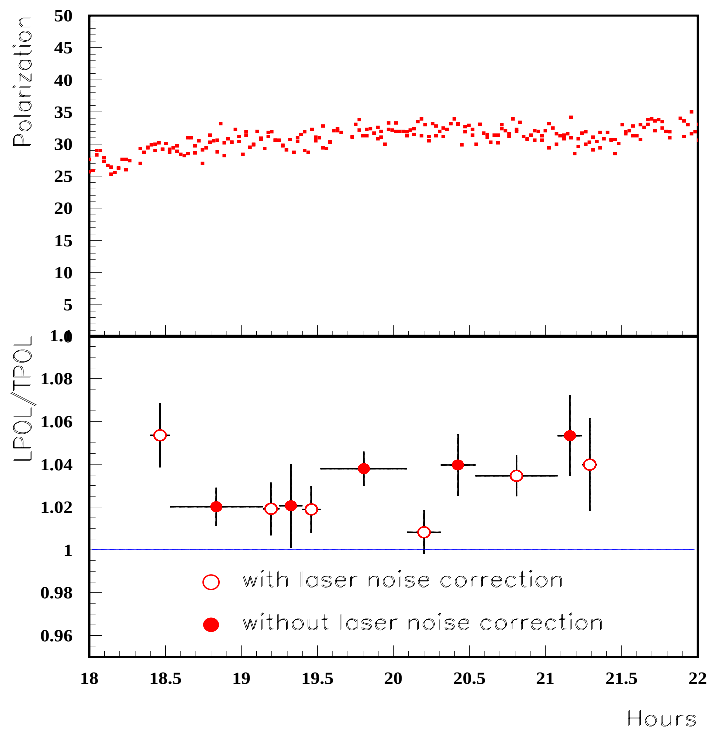

Figure 11: Results of polarization measurement with (by laser firing also on empty bunches) and without (by laser firing on filled bunches only) the laser noise correction are in agreement to each other, resulting in no significant affecting by laser noise.

7 False Asymmetry

To verify that no false asymmetry of the integral energy deposition for left and right circular polarized photons is generated, polarization measurements have been taken with the crystal calorimeter while switching the Pockels Cell off. The scattering of linear polarized laser light off positrons should result in a zero asymmetry measurement, eq. 1.

The results of such a study taken on January 19^{th} is shown in Fig. 12. The measurements have a mean value of 0.02 and an estimated error on the mean of 0.11, indicating that no false asymmetry is generated by the hardware.

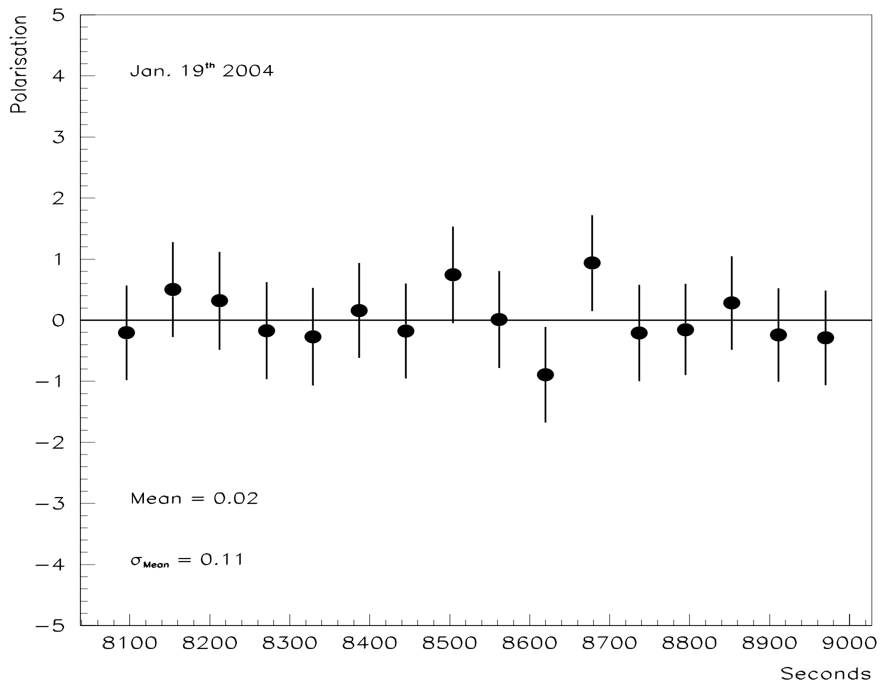

Figure 12: The polarization measurement taken on January 19^{th} shows no false asymmetry generated by the $LPOL$ hardware while using the crystal calorimeter.

8 Conclusions

During winter 2003 and spring 2004, systematic studies have been performed in order to evaluate the realibility of the polarization measurements taken by the Longitudinal Polarimeter at HERMES. The more significant results are described in this report showing no particular systematic effects which could affect such measurements.

As expected, they confirm the results obtained by previous studies and calibrations. In particular, no dependence of the polarization measurement was found on the energy deposition in the calorimeter, and by displacing the calorimeter around the scattered Compton cone. The polarization measurement has been found to be not affected by any calorimeter offset within normal working conditions. Also, the noise from laser firing, and global hardware offsets were shown not to affect the measurement.

The results of these studies do not show any anomalous behavior of the Longitudinal Polarimeter, similar to the performance observed during the 2000 data taking. The polarization measurement appear to be stable within 2%, therefore consistent with the systematic uncertainty value 1.6% obtained from previous studies and cited in [1]- [2].

The LPOL was found to work properly and is not the source of the disagreement between the LPOL and TPOL measurements. A strong correlation between the beam size seen by the TPOL and the ratio LPOL/TPOL has been observed, where the beam size is the vertical size of the scattered Compton photons cone measured at the TPOL calorimeter. The larger this size is, the larger the ratio LPOL/TPOL is.

A rescaling of the TPOL measurement to the LPOL data is not desirable, otherwise the two polarimeters would not provide independent measurements any more. Instead, an off-line analysis and Monte Carlo studies are currently in development by the TPOL analyzers, in order to understand the observed correlation and provide a proper correction for the TPOL polarization measurement.

References

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[2] F. M. Menden, Determination of the Gluon Polarization in the Nucleon, PhD Thesis 2001, DESY-THESIS-2001-060.