A New Sampling Calorimeter for the Longitudinal Polarimeter at HERMES

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Abstract

Based on the prototype Sampling Calorimeter, a new sampling calorimeter has been designed, built and tested for use with the Longitudinal Polarimeter. From a design perspective the new device shows improved resolution over the Crystal Calorimeter presently in use. The enhanced resolution allows for both single and multi-Compton photon mode operation. Additionally, the new device incorporates a great deal of symmetry giving uniformity in both the horizontal and vertical directions. While a separate position sensitive device monitors the beam, the uniformity ensures stable performance in cases where the beam drifts away from the center. Testing of the device in both the DESY test-beam and HERA ring confirmed the Monte Carlo predicted performance.

Contents

1 INTRODUCTION:

The Longitudinal Polarimeter (LPOL) Group at Hermes expressed interest in improving the performance of the LPOL. Following the testing of a prototype sampling calorimeter, the LPOL group decided that a redesign of the existing calorimeter device would improve the determination of the electron beam polarization. For the new device, the most important objectives included good uniformity, a resolution that would make single-Compton measurement possible, as well as long-term gain stability. The existing setup involved a four Crystal Calorimeter feeding light into separate Photo Multiplier Tubes (PMTs). While the design of the Crystal Calorimeter gave accurate knowledge of the beam position, making a separate position sensor unnecessary, it lacked the resolution needed to do single-Compton measurements making it necessary to check the long-term gain stability in a testbeams.

1.1 Objectives for New Sampling Calorimeter:

A prototype calorimeter was designed, built and tested by Joachim Seibert from the University of Freiburg. Following the testing of the prototype sampling calorimeter, plans to build a similar device began. Monte Carlo (MC) simulations [1] revealed that splitting the plates of the prototype in half would enhance resolution to an extent suitable for single-Compton measuring. The prototype response function could also be made uniform by introducing wavelength shifters on all four sides. Finally, simplification of the design was accomplished by feeding the four outputs into a single PMT.

1.2 New Design:

In the prototype design twelve 2.63mm scintillating plates along with twelve 6.0mm tungsten plates formed the sampling volume. Separate PMT's read out signals from two wavelength shifters placed along the top and right side of the sampling volume, giving the device an inherent non-uniformity. Testing the device revealed that a small amount of longitudinal shower leakage entered the PMT. All of these factors were carefully considered during the redesign phase. Figure 1 shows the outcome of redesigning of the prototype.

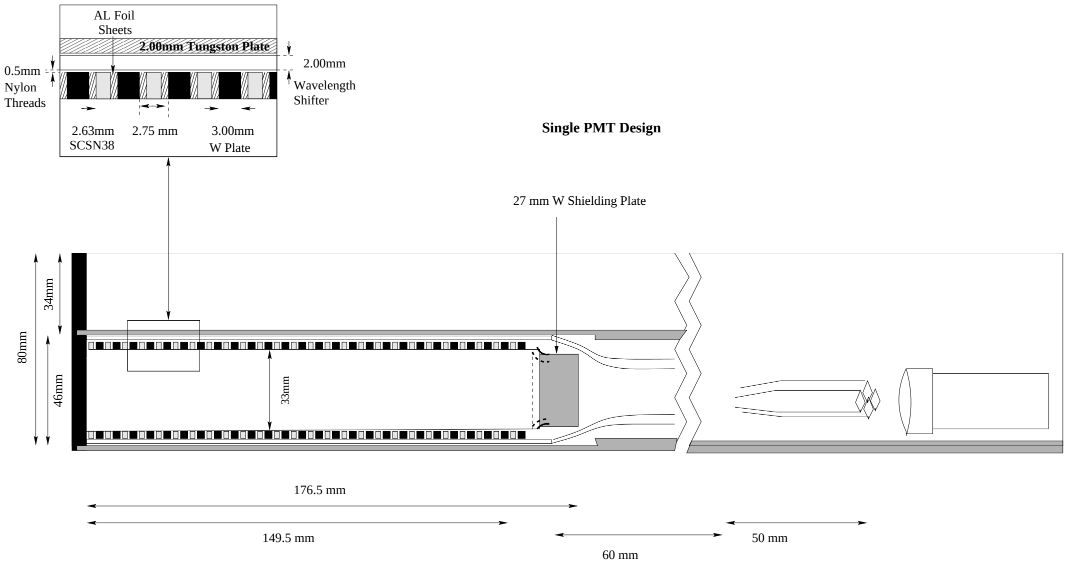

Figure 1. Top view of the New Sampling Calorimeter.

Improvements in the new design include: four sided readout for uniformity, 24 tungsten plates for improved resolution, and 27mm of additional shielding to reduce shower leakage into the PMT by a factor of 60 over the prototype - giving only 0.02% of the signal in the PMT attributed to longitudinal shower leakage.

2 TESTING:

Once the new calorimeter had been assembled, a series of tests had to be conducted to both calibrate the new device and to verify its performance. At this stage, it was important to confirm the MC predictions as well as demonstrate that the device could measure an asymmetry consistent with the working Crystal Calorimeter. As the first set of these tests were conducted in the DESY Testbeam Facility they served mainly to confirm the MC results. Introducing the device into HERA and alternating between the Sampling and Crystal calorimeters gave a way of checking the consistency between the two devices.

2.1 DESY Test Beam:

Testing of the new calorimeter began at the DESY Testbeam Facility in July 2000. The DESY Testbeam produces monoenergetic electron beams ranging from 1 to 6 GeV. The device sat on top of a moveable table, which allowed horizontal and vertical scans to be performed. Prior to the actual testing of the device, simulations of the performance already predicted improvements over the prototype design.

2.1.1 Energy Linearity:

Figure 2 shows the result of the energy scan in the DESY testbeam.

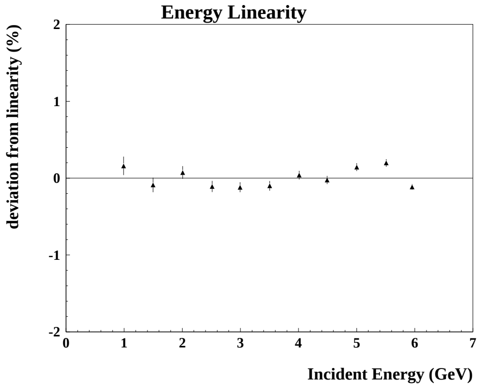

Figure 2. Energy Linearity of the New Sampling Calorimeter as measured in the DESY Testbeam Facility.

The device showed linearity to about 0.2% over the full range of 1 to 6 GeV used at the DESY Testbeam Facility. While the testbeam is capable of accessing lower energies, fluctuations in magnet current used to select the beam energy produce a significant nonlinearity below 1 GeV.

2.1.2 Energy Resolution:

For Sampling Calorimeters, the resolution scales with the inverse square root of the energy. Equation (1) gives the exact relationship as

$$\frac{\sigma}{E} = \frac{\alpha}{\sqrt{E(\mathrm{GeV})}} + \beta. \tag{1}$$

A comparison between the MC simulations and the actual performance (Fig. 3) revealed just how accurately the MC predicted the outcome of measurements. Fitting the measured detector response as a function of energy (E) yields the parameters α and β, which are given in Table 1.

Table 1. Comparison of Testbeam and Monte Carlo resolutions. The parameters α and β are defined in Eq. 1.

	Measured	Simulated
α	$16.0\% \pm 0.17\%$	$15.6\% \pm 0.14\%$
β	$-0.31\% \pm 0.11\%$	$0.14\% \pm 0.07\%$

The measured parameters are almost identical to those predicted by MC.

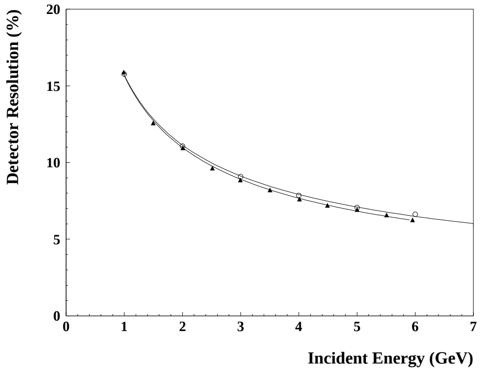

Figure 3. Resolution as a function of energy for single-Compton events from 1 to 6 GeV at the DESY Testbeam compared with Monte Carlo predictions. Note that the testbeam data, represented by solid triangles, were collected in 0.5GeV steps, whereas the MC simulations, represented by open circles, were done in 1GeV steps.

2.1.3 Uniformity Scans:

Because the HERA beam near the LPOL IP point can drift both vertically and horizontally, uniformity in both directions took high priority in the redesign phase. Actual scanning in both directions showed remarkable agreement with the MC predictions as seen in Figure 4.

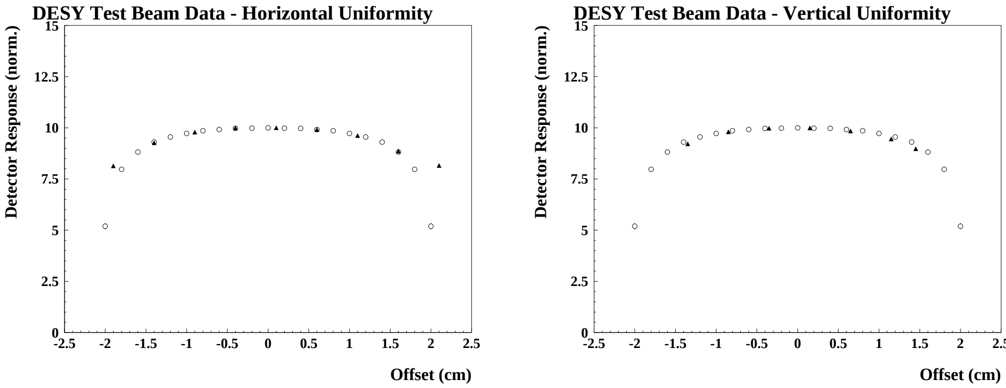

Figure 4. Results of uniformity scans in the horizontal and vertical directions taken at 3 GeV. The solid triangles represent measured data while the open circles represent MC simulations.

The device showed less than 5% deviation from linearity for up to $\pm$10mm. This level of uniformity agrees well with the MC predictions ($\pm$12.5mm).

2.1.4 Preshower Scan:

One feature missing from the redesigned calorimeter was the ability to measure the position of the beam. For this purpose a separate Scintillating Fiber (SciFi) Detector was developed. Because the SciFi Detector required additional shielding in the front, the new calorimeter was tested with a preshower of 6mm lead to evaluate its performance. The results of the preshower test appear in Fig. 5 and Table 2.

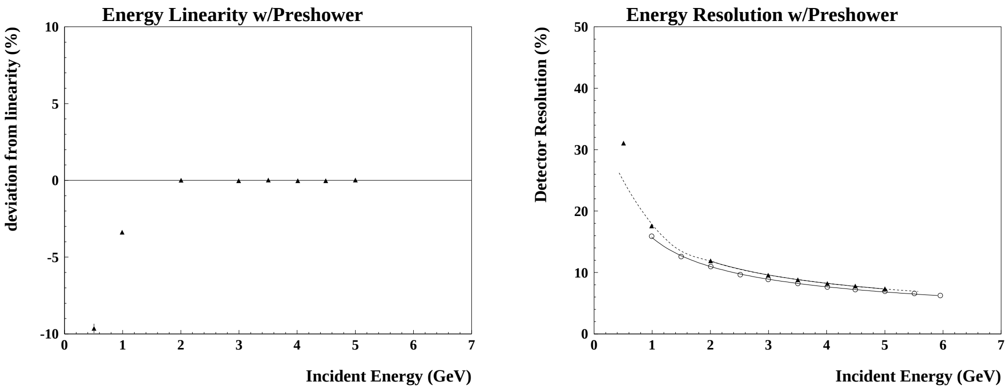

Figure 5. Energy linearity and resolution for the New Sampling Calorimeter with a 6mm lead absorber in front (solid triangles). The open circles in the right figure represent the data without the lead absorber.

The results of fitting the measured resolution from 2 to 5 GeV, where the response still behaved linearly, have been extrapolated and are given by the dashed line. One can see that the energy resolution degrades, with the introduction of the preshower, by at least 2.2%. Notice that below 2 GeV the linear model fails to describe the observed response.

Table 2. Comparison of resolution of New Sampling Calorimeter with and without a 6mm lead absorber in front of the detector. The parameters α and β are defined in Eq. 1.

	Preshower	No Preshower
α	$17.5\% \pm 0.45\%$	$16.0\% \pm 0.17\%$
β	$-0.51\% \pm 0.25\%$	$-0.31\% \pm 0.11\%$

2.2 HERA Testing:

While the DESY testbeam gives accurate information about the lower end of the energy response, the real Compton spectrum from the backscattered photons in HERA range up to 13.6GeV or approximately one-half the energy of the positron beam. The ultimate test of the new calorimeter came from placing the device into the HERA tunnel and studying its performance. The August 4^{th} shutdown was the first opportunity to introduce the new device following the testbeam studies.

The first test was to verify that the measured asymmetry from the new calorimeter agreed with that of the Crystal Calorimeter. While the DESY Testbeam Facility produces an almost monoenergetic, narrow beam of up to 6GeV with a full width at half maximum of about 3mm, the Compton scattered beam in HERA covers the full range of energies up to 13.6GeV and has a highly non-gaussian distribution on the calorimeter surface [1]. Uniformity scans were again performed in HERA and compared to the MC predictions. Though the LPOL was designed for multi-Compton measurements, by reducing the laser intensity it was possible to study the behavior in both the single and multi-Compton modes.

2.2.1 Multi-Compton Mode:

Originally, the LPOL was setup to operate in multi-Compton mode, measuring about 1000 Compton photons per pulse. As the new device would operate in both the single and multi-Compton modes, it employs a more sensitive PMT than either the prototype or the Crystal calorimeters. Careful adjustment of the gain on the PMT allowed the device to be introduced in place of the Crystal Calorimeter. Alternating between the Crystal and New Sampling calorimeters showed that the new device's measure of polarization agreed remarkably well with that of the Crystal Calorimeter, as shown in Fig. 6.

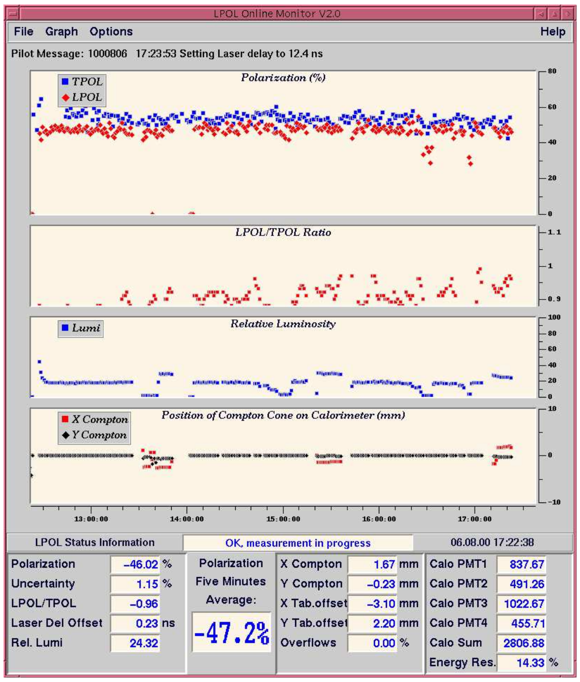

Figure 6. Online Monitor of the polarizations showing LPOL measurement in red and TPOL measurement in blue. The LPOL calorimeter is switched between the Sampling and Crystal calorimeters.

Analysis of the measured polarization showed that the new Sampling and Crystal calorimeters agreed very well within the limited statistical precision of the collected data. Figure 7 shows a comparison between the mean measure of polarizations of the two devices. The overall mean from comparing adjacent points is 0.9975 ± 0.0039.

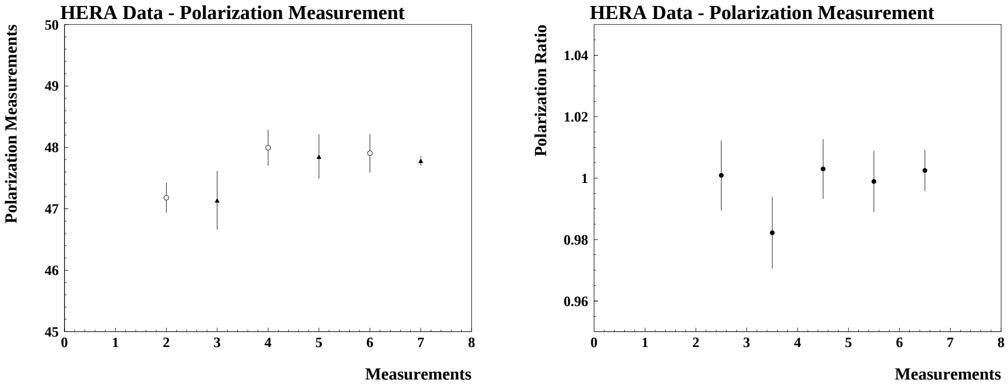

Figure 7. A comparison between the measured polarizations of the Sampling and Crystal calorimeters appears on the left with the ratio of adjacent points on the right.

Note that the identical analysis software is used for this comparison and that no fudge factors have been introduced to the analyzing power of either calorimeter.

2.2.2 Uniformity Scans:

Uniformity scans were conducted while the new device operated in the HERA electron ring. The results appear in Fig. 8.

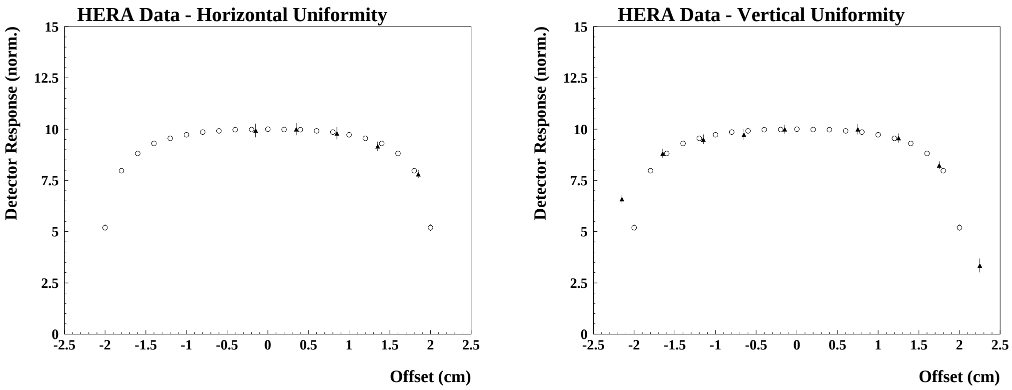

Figure 8. Horizontal and vertical uniformity scans in HERA. The solid triangles represent measured data while the open circles represent MC predictions.

Due to restrictions in horizontal motion, only one half of the horizontal scan could be performed. The new Sampling Calorimeter showed a less than 5% change in its response for up to $\pm$10mm. These results are comparable to what was found in the testbeam and the predicted behavior ($\pm$12.5mm) from the MC studies.

2.2.3 Single-Compton Mode:

Data in single-Compton mode were collected to compare the detector response to a simulation of the Compton cross section that takes detector resolution and realistic background conditions into account.

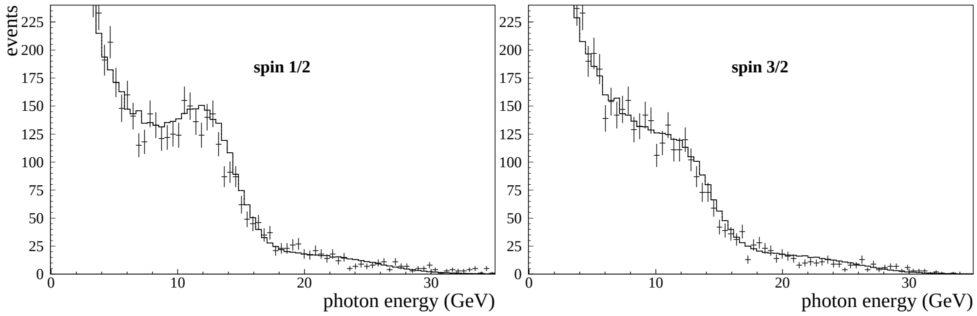

Figure 10. Energy spectra for the Crystal Calorimeter collected in single-Compton mode for the spin-$\frac{1}{2}$ and spin-$\frac{3}{2}$ configurations at a beam polarization of 51%. The solid line is the result of a simulation [2] for a Compton (bremsstrahlung) rate of 0.02 (0.06) per bunch.

The Compton spectrum for the Sampling Calorimeter in Fig. 11 shows a distinct edge. Compare the Compton spectrum in Fig. 11 to the spectrum observed with the Crystal Calorimeter in Fig. 10.

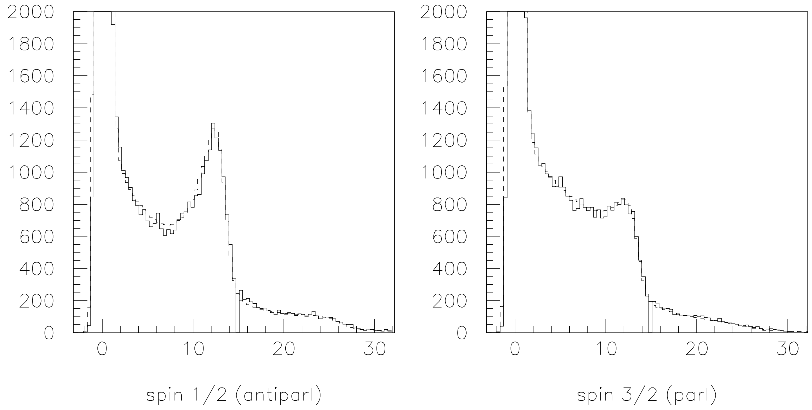

Figure 11. Energy spectra the New Sampling Calorimeter collected in single-Compton mode for the spin-$\frac{1}{2}$ and spin-$\frac{3}{2}$ configurations at a beam polarization of 56%. The dashed line is the result of a simulation [2] for a Compton (bremsstrahlung) rate of 0.40 (0.03) per bunch.

Due to the poor resolution of the Crystal Calorimeter, as shown by the lack of a distinct Compton edge, polarization measurements in single-Compton mode are almost impossible with the Crystal Calorimeter. Single-Compton mode is certainly not a pratical mode of operation to extract the electron beam polarization with high accuracy in a few minutes.

Figure 12 shows a bremsstrahlung spectrum collected with large statistics. Analysis of the derivative of the detector response function near the kinematic limit can provide an additional energy calibration for the device.

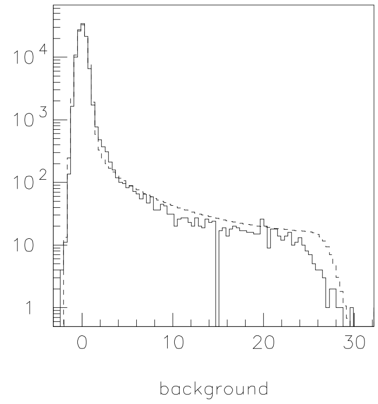

Figure 12. Bremsstrahlung spectrum the New Sampling Calorimeter collected in single-Compton mode. The dashed line is the result of a simulation [2] for a bremsstrahlung rate of 0.03 per bunch.

The background shown here, on a logarithmic scale, falls more rapidly than expected; but overall is well reproduced by the MC studies.

3 CONCLUSIONS:

With all of the testing completed, the performance of the new device looks consistent with Monte Carlo predictions. The outcome of the tests reveal an energy linearity of approximately 0.2%, an energy resolution of 16%, a detector response uniformity of 5% over a range of $\pm$10mm, and an agreement with the Crystal Calorimeter in the polarization measured in multi-Compton mode to better than 0.5%.

There remains one more test to be done. Since a change of the position or slope of the electron beam in HERA can result in a shift of the Compton photon distribution away from the center of the calorimeter, one has to measure the polarization as a function of this offset. The Monte Carlo simulations in Ref. [1] suggest that the polarization should be very stable within the typical operating range of the LPOL of $\pm$5mm.

References

[1] A. Raj and W. Lorenzon, Internal Polarimeter Report IPR-00-01. "GEANT Monte Carlo simulationsfor a Sampling Calorimeter.

[2] C. Pascaud and F. Zomer, Internal Report, Orsay, April 13, 1999, "Likelihood treatment of Polarisation Measurements" and private communications.