Photodetector Studies for Polarimetry

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Experiences from other Compton polarimeters show that their precision is limited by the linearity of the Cherenkov detector. A test bench has been set up to study various types of photodetectors. Several methods have been established in order to measure non-linearities with a precision of 10^{-3}. First results are shown in the talk [1]. Furthermore, a high-precision method to measure non-linearities of a QDC is presented.

1 Introduction

At the International Linear Collider (ILC) it is planned to use polarized electron and positron beams. In order to fully exploit the physics potential, the polarization has to be measured with an as yet unequaled precision of at least 0.25% [2]. The proposed polarimeters, consisting of spectrometer chicanes and subsequent Cherenkov detectors, make use of the polarization dependence of Compton scattering, where the energies of the recoil electrons depend on their polarization relative to that of the laser photons. On the order of 1000 beam electrons are scattered per laser interaction. The energy distribution of the scatterd electrons is transformed into a spatial distribution which is then measured by a multi-channel Cherenkov detector (figure 1). A precise determination of the beam polarization is achieved by measuring the asymmetry of the spectra obtained by switching the laser polarization between +1 and -1.

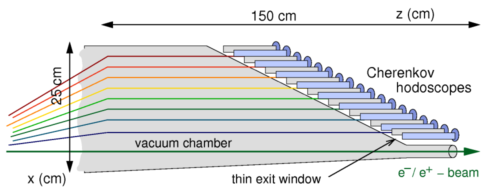

Figure 1: Multi-channel Cherenkov detector; top view

Experiences from previous polarimeters show that the limiting factor of this method will not be of statitical but systematic nature. The linearity of the entire Cherenkov detector, and especially of the photodetector (PD) is of utmost importance [3, 4].

2 Cherenkov Detector Layouts

There are various design options for the Cherenkov detectors: one uses gas tubes (cross section 1 cm^2) filled with C_4F_{10}, which has a high Cherenkov threshold of about 10 MeV. The light is detected by a conventional photomultiplier tube (PMT). Alternatively, one considers using different types of PDs, like a multi-anode photomultiplier (MAPM). The MAPM not only fits the rectangular cross section of the gas tubes perfectly, but also has multiple anodes, that can be read out independently. An issue may be cross talk between the cathodes. This will have to be studied. A novel design envisions the use of a silicon based photomultiplier (SiPM). This recent development shows excellent single photon detection capabilities, and also outmatches the more conventional PDs in terms of robustness, size and cost. Due to its compactness (some mm^2) a much higher spatial resolution can be achieved, and thus a more precise polarization measurement. The downside, however, is that the gas tubes have to be substituted by quartz fibers, which have a low Cherenkov threshold (some keV) and could thus be susceptible to background radiation.

3 Test Bench

A test facility has been set up to analyze different types of PDs regarding their adequacy for an ILC polarimeter. It consists of a light-tight box, that can be equipped with different types of PDs. A schematic of the box can be seen in figure 2. The light is generated by a blue LED ($\lambda = 470$ nm) connected to a function generator. The data acquisition is done via VME electronics using a high resolution double range 12-bit QDC (200 and 25 fC LSB). The following types of PDs are available for these studies and can be mounted in the box: conventional PMTs, 2x2-MAPMs, 1x1 cm^2 SiPMs (400 and 1600 pixels), and 3x3 cm^2 SiPMs (3600 pixels).

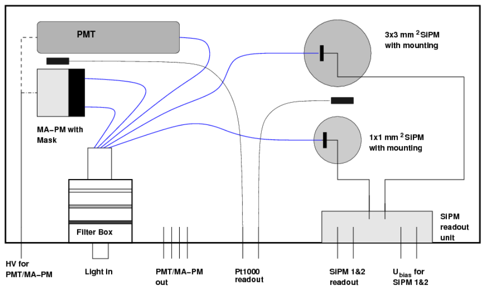

Figure 2: Schematic of the light-tight box

4 Linearity Measurements

4.1 QDC

A considerable non-linearity may be introduced by the QDC. The *Histogram Testing Method* is used to determine the integral and differential non-linearity (INL and DNL). A full-scale range (FSR) sine wave ($f = 10$ Hz) is used as input signal. No sawtooth or ramp function is used in order to avoid artefacts from the function generator. The readout is triggered by a 50 ns random gate. 25 million samples are acquired. The code probability density for an ideal QDC is given by $P(i) = N/\pi \cdot \sqrt{(A/2)^2 - (i - (A/2))^2}$, where i, A and N are the QDC bin number, the amplitude of the input signal and the number of samples respectively. The ratio of the measured and the ideal code probability density is equal to the code bin width. This, in turn, gives the DNL, which is the deviation from the ideal code bin width of 1 LSB. The result is shown in figure 3. The device shows good linearity over the entire range.

The INL for each QDC bin can then be calculated by summing the DNL up to that bin. Finally the distribution has to be corrected for gain and offset to be 1 and 0 respectively. The result is shown in figure 3. The maximum INL is about 4 LSB, which is 0.1 % FSR, in compliance with the manufacturer's data sheet, and will be corrected for.

4.2 Photodetector

The measurements described in the following have been made using a 2x2-MAPM. Each measurement consists of one million single events. The recorded QDC spectrum is fitted by a modified Poisson function, so that the number of incident photoelectrons can be determined.

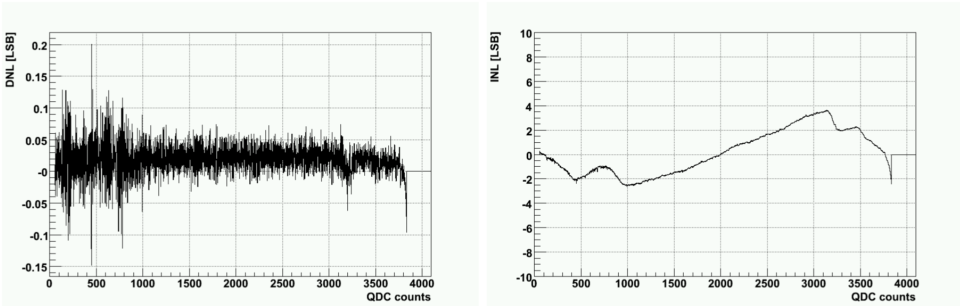

Figure 3: QDC non-linearity: left) DNL; right) INL

The reduced χ^2 value of the fits is generally very good. As stated above, the linearity of the PD is crucial to the precision of the polarization measurement at the ILC. The relation between light yield and bias voltage of the LED is not calibrated. To measure the PD linearity four different methods have been established that are independent of the absolute scale of the LED. They will be discussed in the following sections.

4.2.1 Optical Filters

This is the most widespread method to determine the linearity of a PD. The LED light is attenuated by calibrated optical filters. By comparing the different measurements one can determine the device's INL. Three different filters have been used allowing for eight combinations of filters. The results can be seen in figure 4. However, due to insufficient knowledge of the transmittance of the filters, the errors on the result are about one percent, and completely dominated by systematics. For the time being this method cannot be used to determine the linearity of the PDs with the desired precision unless the filters can be recalibrated.

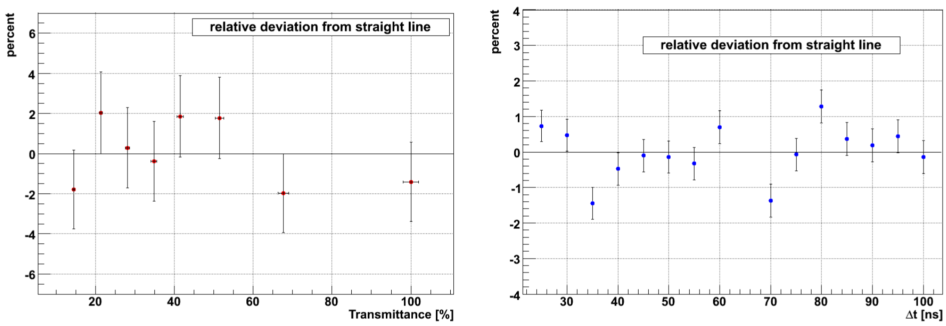

Figure 4: Deviation from linearity: left) optical filters method; right) LED pulse method

4.2.2 LED Pulse Length

The LED is pulsed by a rectangluar pulse from the function generator. The length of the pulse is varied ensuring a linear variation of the amount of light on the photocathode. Note that it is crucial to keep the minimal pulse length much larger than the rise and fall time of the LED. This method also measures the INL of the PD. The pulse length has been varied in 5 ns steps between 25 and 100 ns. The results can be seen in figure 4. The errors are clearly too large (≈ 0.5 %). However, as opposed to the previous method, they are not limited by systematics, since the function generator allows very precise adjustments, but by statistics. Thus the number of single events per measurement needs to be increased. However, recent Monte Carlo studies show that a reduction of errors can also be achieved by using a more elaborate fit method.

4.2.3 Double Pulse

This method allows to detemine the DNL of a PD. Two different LED pulses are used: $p \ll P_i$. The PD's response is measured for P_i and $P_i + p$. By varying P_i the DNL of the PD can be determined for its entire range. This method has not been realised yet.

4.2.4 Mask

A second approach to measure the DNL uses a four-holed mask applied to the PD. An LED pulse is equally fed into four optical fibers, which can be applied to the four holes in the mask. The PD's response is measured seperatly using only one fiber at a time (P_1,...,P_4) and finally using all four together (P_0), giving DNL $= (P_1 + P_2 + P_3 + P_4)/P_0 - 1$. This method has not been realised yet.

5 Conclusion and Outlook

The linearity of the photodetectors in the Cherenkov hodoscope is a crucial requirement for high precision polarimetry ($\Delta P/P = 0.25\%$) at the ILC. A test bench for photodetector studies has been set up. Different methods to measure the linearity with the desired precision have been established and tested with an multi-anode photomultiplier (MAPM). First results have been shown indicating that the methods are not yet sensitive to non-linearities of the order of 10^{-3}. Monte Carlo studies have been done in order to determine how many single events are needed and to optimize the fit method. As a result of these studies the measurements will be repeated with a more elaborate fit method. Once all methods have been thoroughly checked with the MAPM, further photodetector types will be analyzed and compared to each other.

References

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