SiPMMicro PDE Report

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Abstract

As part of the research and development of Silicon photo multipliers for potential use with the Barrel Calorimeter of the GlueX Project, the University of Regina has been provided with two 3×3 mm^2 A20HD SiPMMicros to be tested. Here the experimental process and results pertaining to a measurement of the SiPMMicro PDE are outlined.

Key words: silicon photomultiplier, photon detection efficiency

1 Introduction

Silicon Photo Multipliers (SiPMs) are being considered for use on the Barrel Calorimeter (BCAL) for the GlueX Project because of their immunity to magnetic fields, low bias voltage (∼30 V) and compact packaging. As part of testing for and working towards feasibility of using SiPMs on the GlueX BCAL, tests have been ongoing at the University of Regina. The latest round of measurements has been focused on determining the photon detection efficiency (PDE) of a 3×3 mm^2 A20HD SiPMMicro provided by SensL.

2 Description of Setup

To determine the PDE of a SiPMMicro, a laser with an SMA fibre output [1] was used to illuminate a short (∼30 cm) green scintillating fibre [2] at its centre,

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[1] PicoQuant PDL 800-B Picosecond Pulsed Diode Laser with LDH-P-C-375B Laser Head

[2] Saint-Gobain BCF-20 Fast Green Scintillator

15 cm along its length (see Figure 1). One end of the fibre was coupled to a calibrated photodiode [3] which was connected to a picoammeter [4] which read its current. The other end of the fibre was coupled to the 3×3 mm^2 A20HD-07 SiPMMicro which was connected to an amplifier board [5]. In each case the fibre was polished using a FiberFin polisher and coupled using a small amount of optical grease.

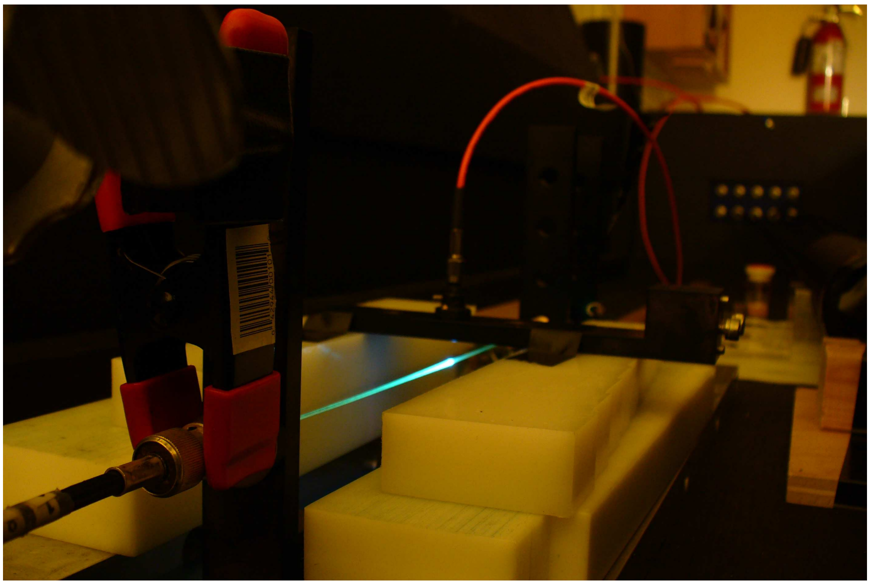


Fig. 1. The laser illuminated the green scintillating fibre at its centre.

Bias voltage was applied to the SiPMMicro by the Keithley voltage source, and voltages of +5 V and -5 V were applied [6] to power the amplifier. The laser was operated at the lowest internally controlled repetition frequency of 2.5 MHz and the laser SYNC OUT was used to start the ADC [7] gate after being passed through a discriminator [8] and a coincidence unit [9] to establish the gate width (all measurements were taken with ADC gate widths of either 120 ns or 160 ns) and lower the event rate (a pulse generator [10] triggered by the laser SYNC OUT was used to produce a ~1 ms pulse which was then used as a veto in the coincidence unit in order to avoid saturating the ADC with events). The SiPMMicro signal was delayed by ~20 ns before being sent to the ADC unit.

[3] Hamamatsu S2281 Calibrated Photodiode
[4] Keithley 6487 Picoammeter/Voltage Source
[5] SensL 2006 spmmini_v2 pulse_amp
[6] Regulated DC Power Supplies GP-1503 and CS13003X111
[7] LeCroy Model 2249A ADC
[8] Phillips Scientific Model 705 Octal Discriminator
[9] LeCroy Model 465 Coincidence Unit
[10] LeCroy Model 222 Dual Gate Generator

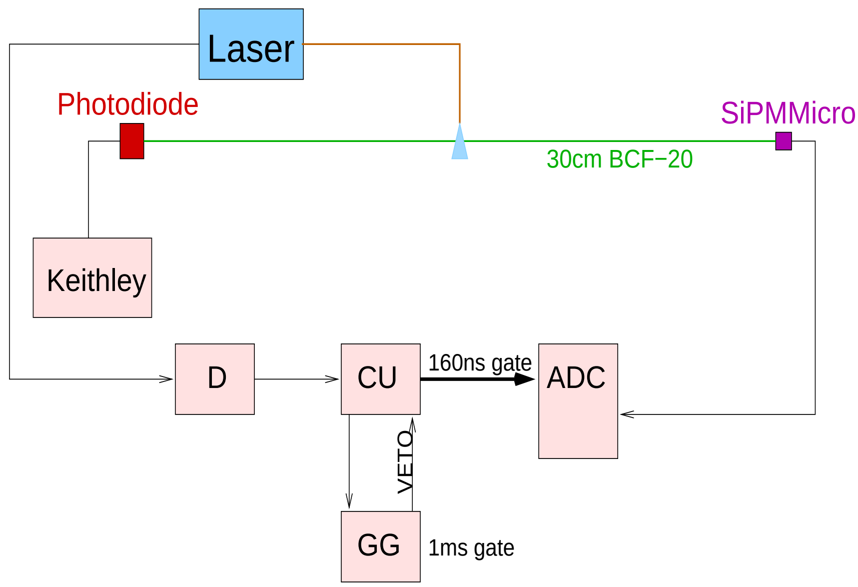


Fig. 2. Experimental setup of the SiPMMicro tests to measure PDE.

3 Measurements

By comparing earlier measurements of the spectral response of BCF-20 fibres[1] to calibration information provided with the photodiode, it was determined that, for the spectrum emerging from a BCF-20 fast green scintillating fibre illuminated 15 cm from its end, the photodiode quantum efficiency was relatively constant at 67%, which corresponds to a photo sensitivity of 270 mA/W (see Figure 3). This information was used to calculate the number of photons present in a laser pulse based on the photodiode current as

$$\frac{Photons}{Pulse} = \frac{I}{E_\gamma S_\lambda f} \tag{1}$$

where I is the photodiode current, E_γ is the energy of a photon of wavelength 500 nm, S_λ is the photo sensitivity of the photodiode at 500 nm, and f is the frequency of the laser pulses.

Adjusting the laser's intensity (arbitrarily labelled from 0 to 10 on the laser), a range from 2.20 to 2.88 was established where the photodiode current was readable (only currents ≥20 pA could be reliably read by the Keithley) and the SiPMMicro signal was not cut off due to saturation (see Figure 4(b)). For each intensity, the photodiode current was taken as the average of 100 readings from the Keithley, and roughly 100,000 events were collected in the ADC spectrum of the SiPMMicro.

For low laser intensities (2.20 to 2.40) individual photoelectron peaks were visible in the SiPMMicro ADC spectra. The number of photoelectrons was

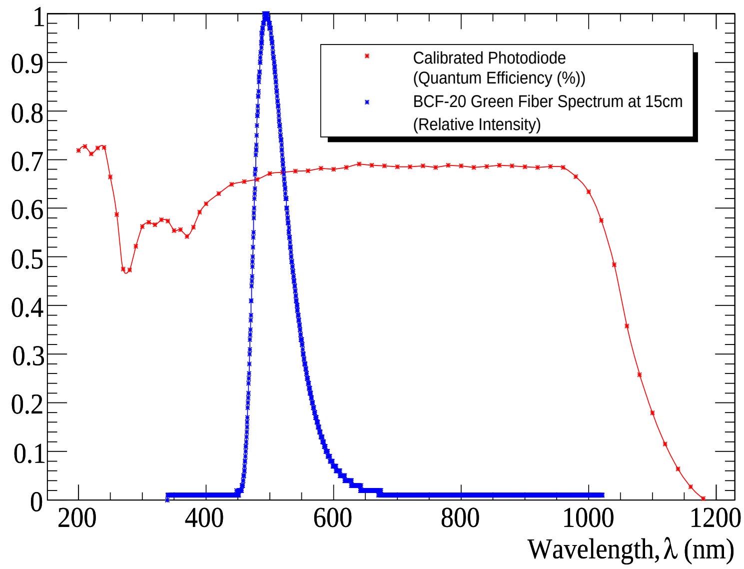
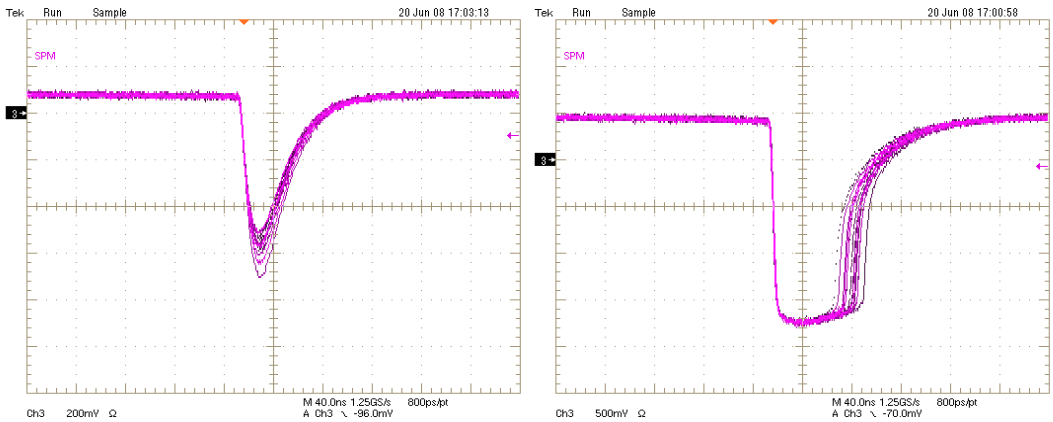


Fig. 3. This plot shows the quantum efficiency of the calibrated photodiode with respect to the relative intensity of the spectrum emerging from a BCF-20 fast green scintillating fibre illuminated 15 cm from its end.

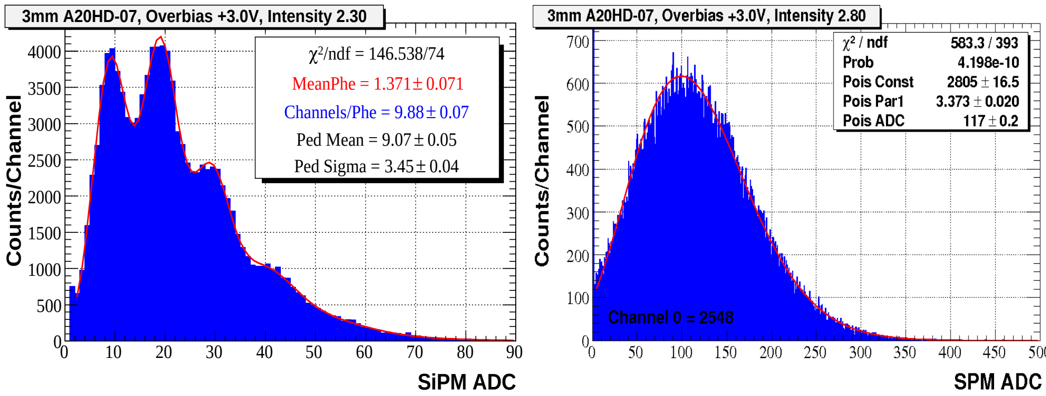


(a) Laser Intensity Setting 2.88

(b) Laser Intensity Setting 2.90

Fig. 4. Sample scope traces from the SiPMMicro at laser intensity settings of (a) 2.88 and (b) 2.90 where the signal is squared off. The major scal division in the horizontal axis is 40 ns, and on the vertical axis it is (a) 200 mV and (b) 500 mV. For the 3×3 mm^2 A20HD SiPMMicro, this saturation occurs for laser pulses with $\gtrsim$1500 photons per pulse.

then fairly easily found by fitting each peak. The pedestal or first peak in the spectra corresponds to zero photoelectrons, the next peak to one photoelectron, and so on (see Figure 5(a)). These spectra are convenient because the pedestal position is easy to identify and the distance between photoelectron peaks can be measured, thus calibrating the ADC scale for higher intensities where individual peaks are not visible.



(a) Laser Intensity Setting 2.30 (b) Laser Intensity Setting 2.80

Fig. 5. Sample ADC spectra at (a) low laser intensity where individual peaks are visible, and (b) high laser intensity where peaks are not visible.

At higher intensities (greater than 2.40) where individual photoelectron peaks were not visible, the number of photoelectrons can be determined as

$$Phe = \frac{ADC_{Mean} - ADC_{Pedestal}}{Channels/Phe} \tag{2}$$

where the ADC_{Mean} value is determined by fitting the spectra with a Poisson distribution, the ADC-channels-to-Number-of-Photoelectrons factor $Channels/Phe$ is determined from low intensity spectra, and $ADC_{Pedestal}$ is the mean value (position) of the zero photoelectron peak (see Figure 5(b)). However, this pedestal position shifts to the negative ADC scale with increased intensity, so determining its position is somewhat problematic.

Looking only at low intensity spectra where individual photoelectron peaks are visible, a simple graph of the number of photoelectrons (from the SiPMMicro ADC) versus the number of photons (from the photodiode current) shows the PDE of the SiPMMicro at overbias +3.0 V and gate duration 160 ns (see Figure 6) to be 9.18 ± 0.33%.

3.1 Pedestal Shift at High Event Rates

Because of the overshoot in the pulse tail as seen in Figure 7, there is an offset in the baseline of the SiPMMicro signal. This results in a shift of the pedestal in the ADC spectra. This offset increases with an increase in pulse amplitude and becomes quite significant at high laser intensities (greater than 2.60). Based on ADC specifications, the expected pedestal shift can be estimated. For the LeCroy 2249A ADC, the full-scale range is 256 pC ± 5% over 1024

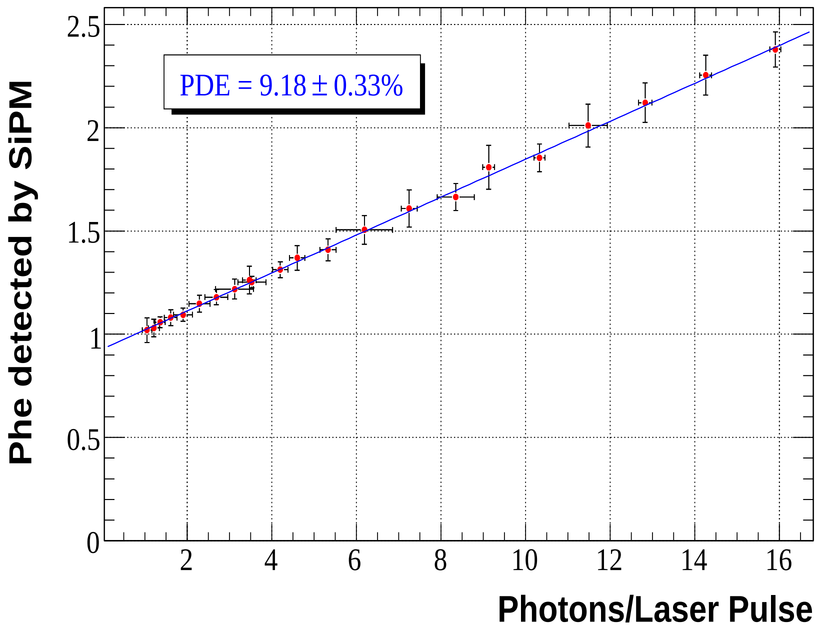


Fig. 6. SiPMMicro 3×3 mm^2 A20HD at low laser intensities (from 2.20 to 2.40), overbias +3.0 V, gate duration 160 ns, and laser frequency 2.5 MHz.

channels, so there are 0.25 pC/Channel. The impedance of the ADC is 50 Ω, so the pedestal position is shifted by a value ADC_{Shift} given by

$$ADC_{Shift} = \frac{Offset}{50\ \Omega}\frac{Gate\ Width}{0.25\ pC/Channel} \tag{3}$$

where the Offset is found by viewing the baseline of the SiPMMicro signal, and the Gate Width is set on the coincidence unit, in this case at 160 ns.

By observing signals on an oscilloscope, the baseline offset was estimated and the expected pedestal shift was calculated. This information was then used to calculate the number of photoelectrons in the spectra. When these data are included, the PDE is 9.00 ± 0.15 % which is consistent with low intensity results (see Figure 8).

While the pedestal shift is significant at the relatively high rate of 2.5 MHz, at the low frequency of ∼1 kHz (achieved by triggering the laser externally using the gate generator) there is no shift even for high laser intensities (see Figure 9). A PDE measurement has not yet been made using low frequency data because the laser is uncalibrated at 1 kHz (at low frequencies the photodiode current is too small to be read by the picoammeter). This work is ongoing and will likely require the use of a calibrated photomultiplier tube (as used in 2 m long scintillating fiber tests at Regina) rather than a photodiode.

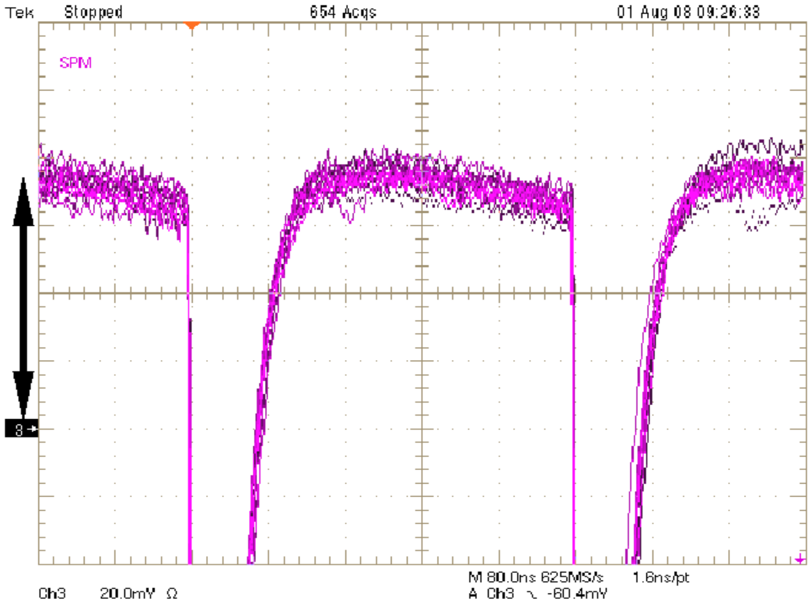


Fig. 7. Sample signal taken with SiPMMicro 3×3 mm^2 A20HD-07 at overbias +3.0 V, laser frequency 2.5 MHz, and laser intensity 2.88. Here an offset of $\sim$ 60 mV is seen in the baseline of the SiPMMicro signal.

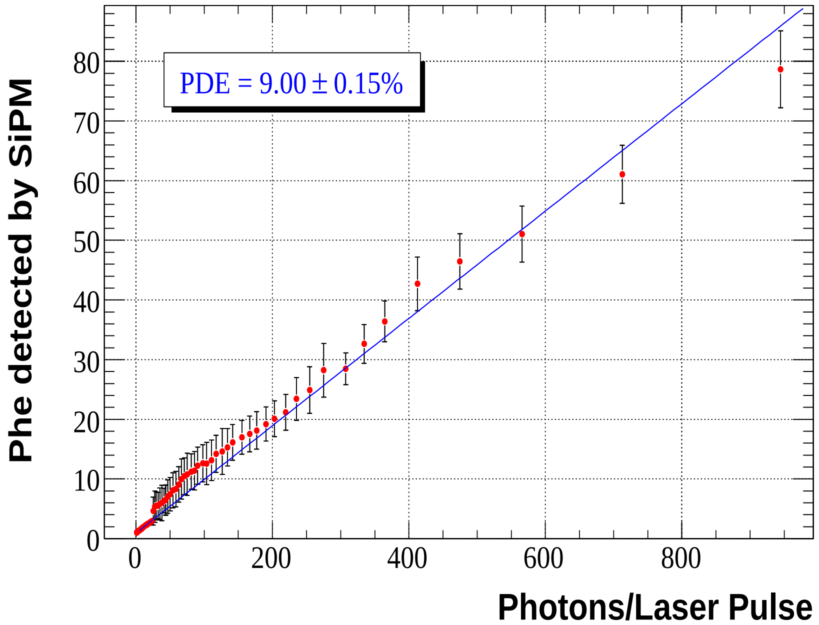
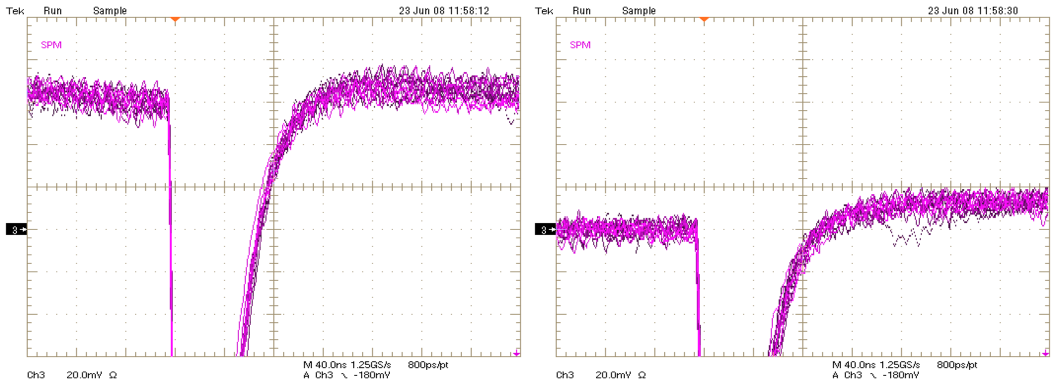


Fig. 8. SiPMMicro 3×3 mm^2 A20HD at overbias +3.0 V and laser frequency 2.5 MHz. Both low intensity and the pedestal-corrected high intensity data are included in the plot.

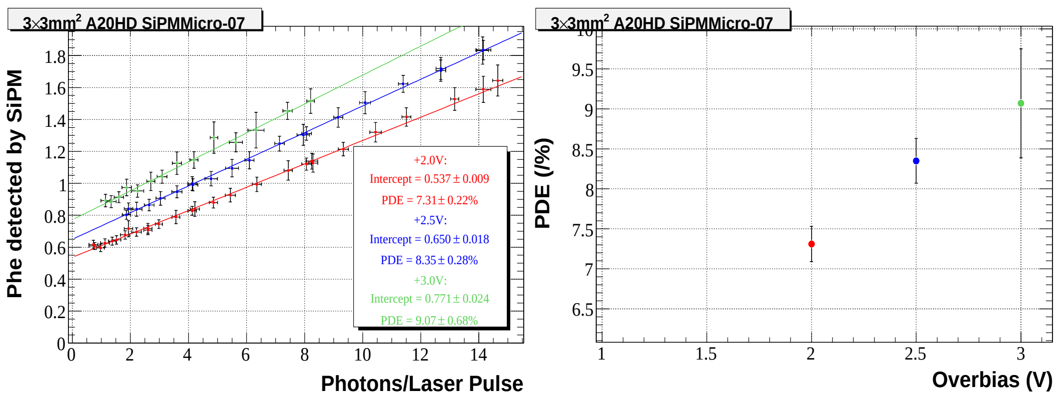
4 Results

The PDE of 3×3 mm^2 A20HD-07 SiPMMicro was measured for overbiases of +2.0 V, +2.5 V, and +3.0 V. These results can be seen in Figure 10.



(a) 2.5 MHz (b) 1 kHz

Fig. 9. Each of these scope traces were taken with laser intensity 2.88 with overbias +3.0 V. Note that there is a baseline offset of ∼60 mV at high frequency, but no noticeable offset at low frequency.



(a) (b)

Fig. 10. SiPMMicro 3×3 mm^2 A20HD-07 at overbias of +2.0 V, +2.5 V and +3.0 V, laser frequency 2.5 MHz, and ADC Gate 120 ns. For each overbias, data are presented only for the laser intensities where individual photoelectron peaks were visible.

From Figures 10(a) and 11, it is obvious that the intercept, or offset (the number of photons produced by noise in the SiPMMicro) varies slightly with bias voltage as well as ADC gate width. From +2.0 V to +3.0 V, this value ranged from 0.537 ± 0.009 to 0.771 ± 0.024 photoelectrons with a gate width of 120 ns. At overbias +3.0 V measurements were taken for gate widths of 120 ns as well as 160 ns. As expected, there is a corresponding increase in the offset with increased gate width (from 0.771 ± 0.024 to 0.929 ± 0.016 photoelectrons). This offset should be subtracted from the average number of photoelectrons estimated from a particular spectrum for a certain set of conditions (overbias and ADC gate width), but care must be taken to ensure that the offset is measured under identical conditions.

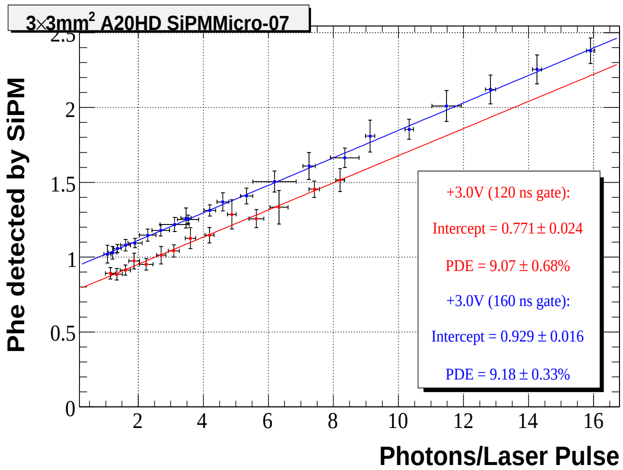


Fig. 11. SiPMMicro 3×3 mm^2 A20HD-07 PDE measurements were taken at overbias +3.0 V with ADC gate widths of 120 ns and 160 ns. The resulting PDEs are consistent with each other, but there is a larger offset (intercept) for the larger gate width.

5 Conclusions

A ∼30 cm fibre illuminated by a laser with a 3×3 mm^2 A20HD-07 SiPMMicro at one end and a calibrated photodiode at the other end was used to determine the PDE of the SiPMMicro at three different bias voltages. The PDE was measured to be 7.31±0.22% at +2.0 V, 8.35±0.28% at 2.5 V, and 9.07±0.68% at 3.0 V.

The overshoot in the SiPMMicro analog signal results in a significant offset of the signal baseline, resulting in an ADC pedestal position shift at high laser intensities for high frequencies. While a pedestal correction based on the baseline offset can be used to determine the number of photoelectrons for high intensity spectra (after this correction, the PDE at +3.0 V was consistent with low intensity results at 9.00 ± 0.15%), this issue requires further investigation.

References

[1] Z. Papandreou, B.D. Leverington and G.J. Lolos, *Spectral response of scintillating fibres*, GlueX-doc-1072-v1, June 2008.