First Report on the Testing of the Phase II 1mm and 3 mm SiPM's

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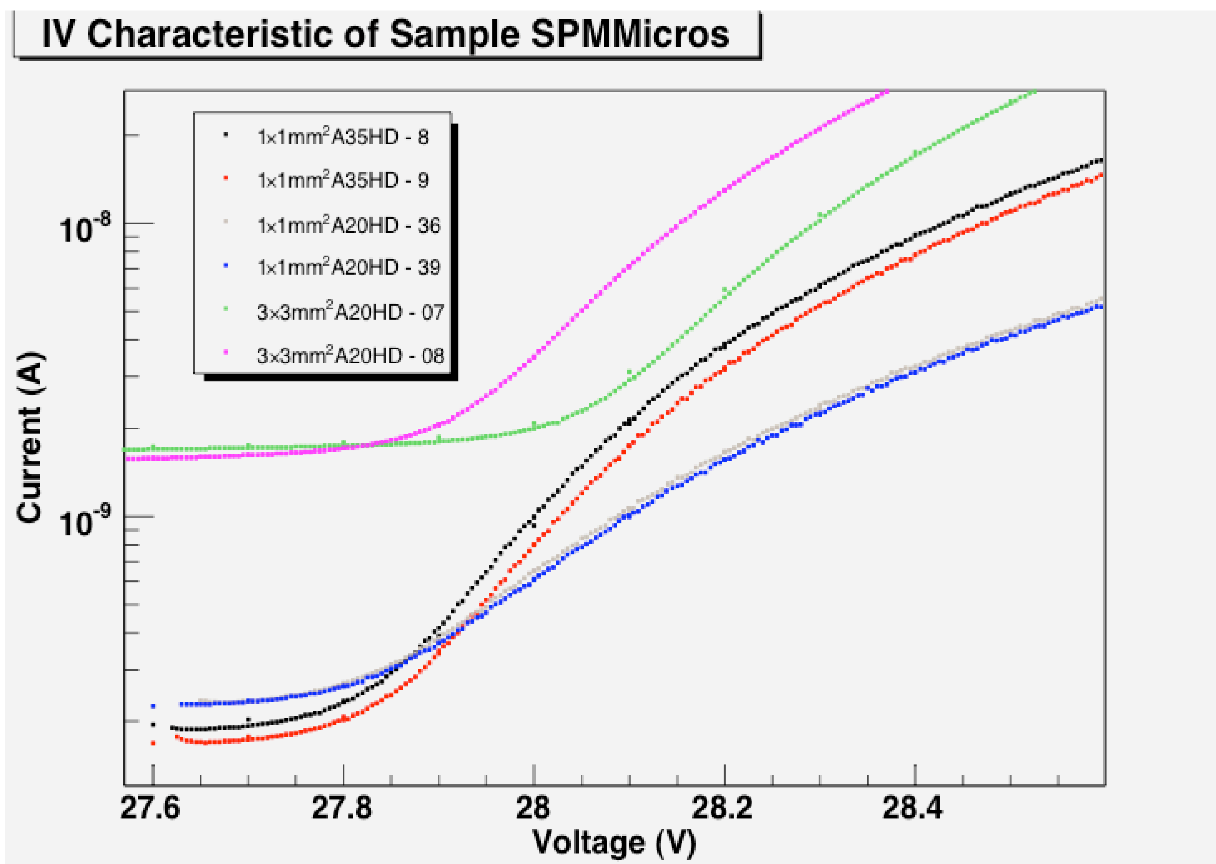
We received two samples of A20HD [1mm x 1 mm] SiPM's (serial numbers 36 and 39), two samples of A35HD [1mm x 1 mm] (serial numbers 8 and 9) and two samples of A20HD [3mm x 3 mm] SiPM's (serial numbers 07 and 08).

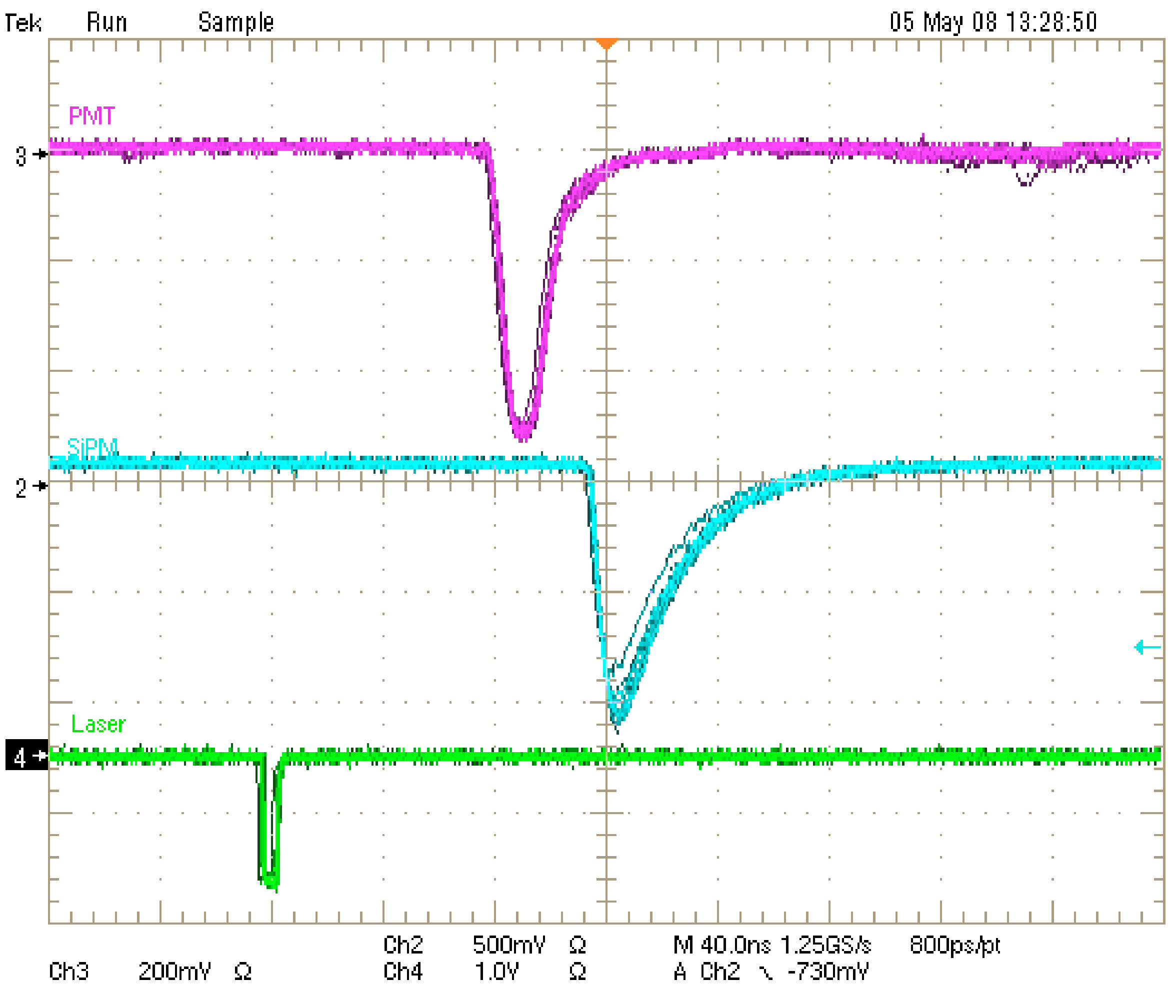
Testing Results

1) ***IV-curves***: We mapped out all their IV-curves to verify SensL's data and to assure that we had functioning devices to do further evaluation. A summary plot is shown below. The A20HD SiPM's (36 and 39) display essentially identical IV-curves shown in blue and grey and identical breakdown voltage. On the other hand, the 3 mm x 3 mm versions (07 and 08) exhibit very different IV-curves. Particularly, serial number 07 has a breakdown voltage approximately 0.2 V higher. Finally, the A35HD SiPM's (8 and 9) exhibit very similar IV-curves with no measurable difference in their corresponding breakdown voltages.

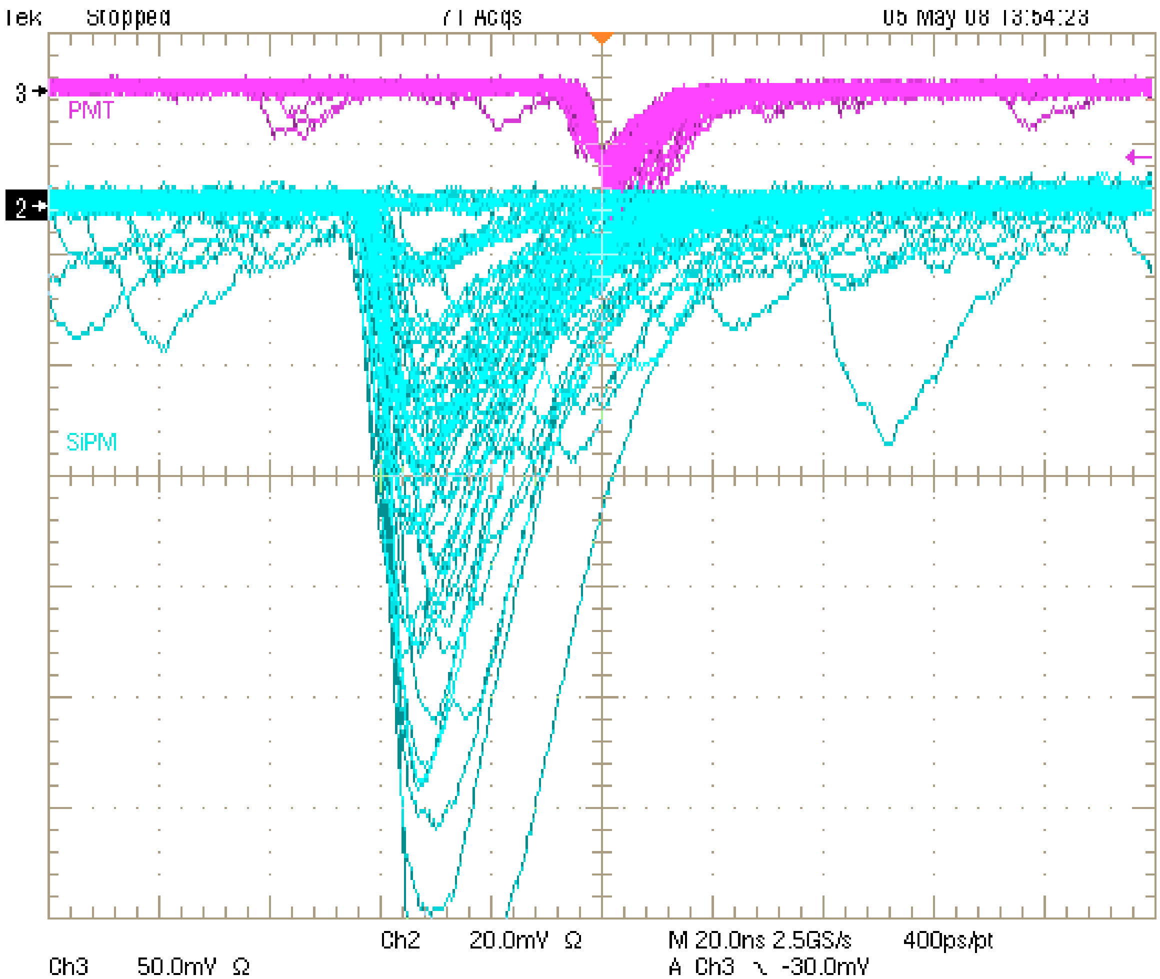


2) ***Testing with Sr90 source***: The set-up consists of a ~ 30 cm long BCF-20 SciFi with one end attached to a calibrated 2" vacuum PMT, while the other end is read out by the SiPM under testing, in this case A20HD (39). So far, no attempt has been made to collimate the source, so the results below are to be considered very preliminary and the first to extract the number of photoelectrons using an electron source, as opposed to UV LED's.

The PMT provided the DAQ trigger. For this, the UV laser was used to check functionality and to set timing gates and the oscilloscope traces of the PMT, the SiPM and the laser trigger output are shown below:

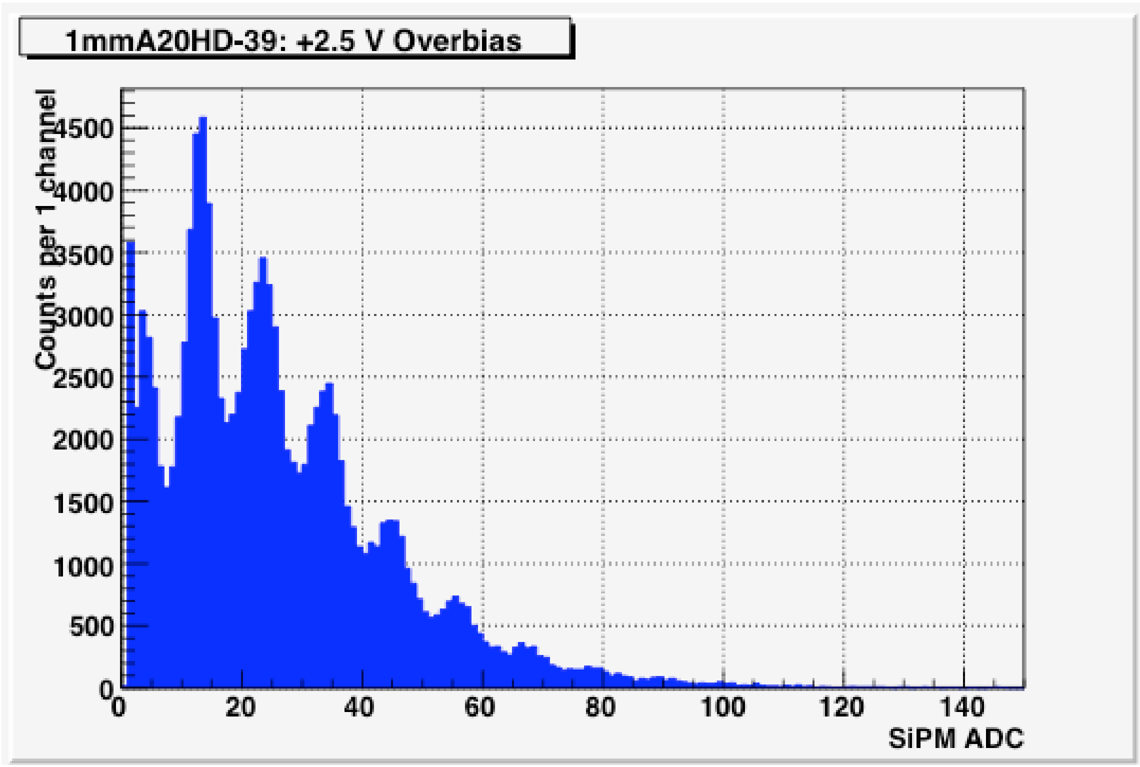


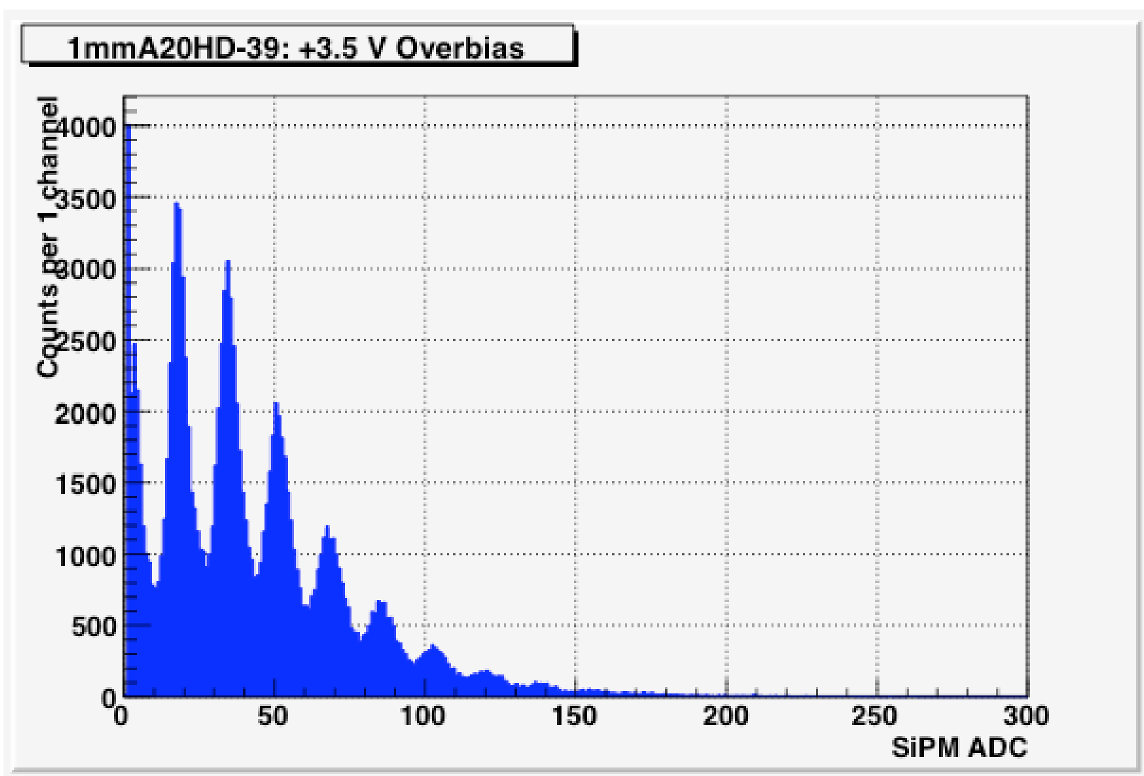
With a 40 ns/division, the SiPM pulse exhibits a rise time of ~ 8 ns from 10% to 90% of the amplitude. The pulse is contained within a ~70 ns time window. As observed, there is no evidence of any "abnormalities" in the shape of the pulse. The oscilloscope trace using the Sr90 source is shown below, where purple is again the PMT trace and cyan is that of the SiPM. One can see the different bands corresponding to a single photoelectron at ~ 10 mV pulse height, and the second and, perhaps, third photoelectron bands.

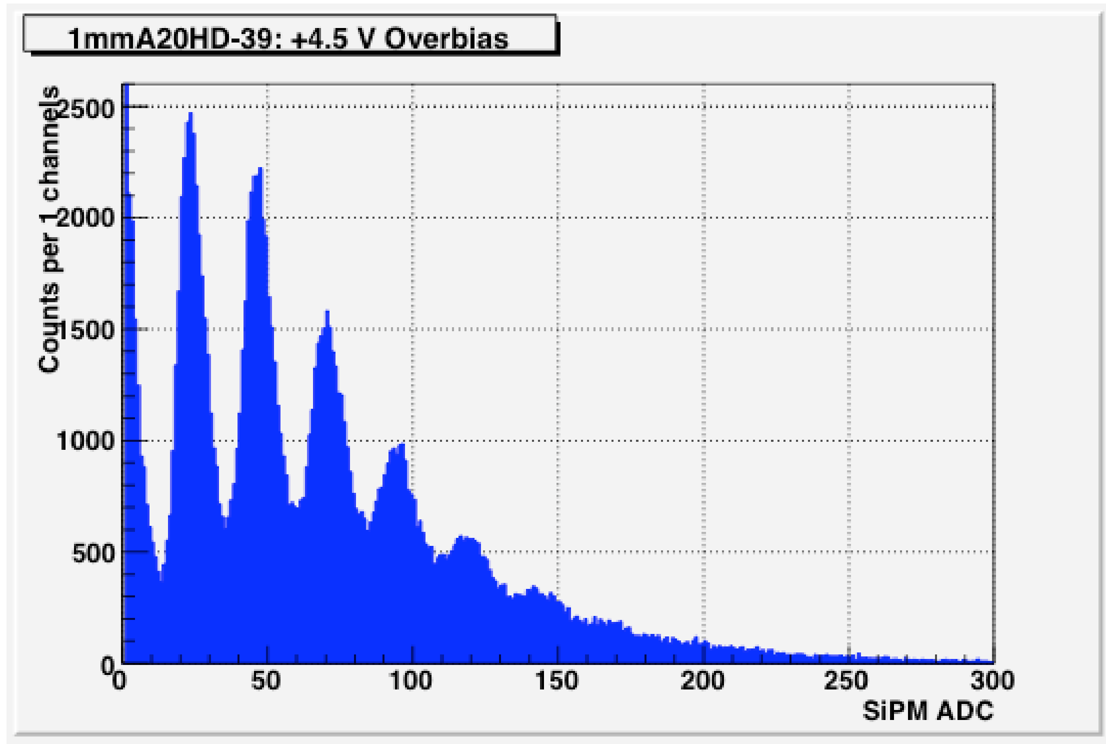


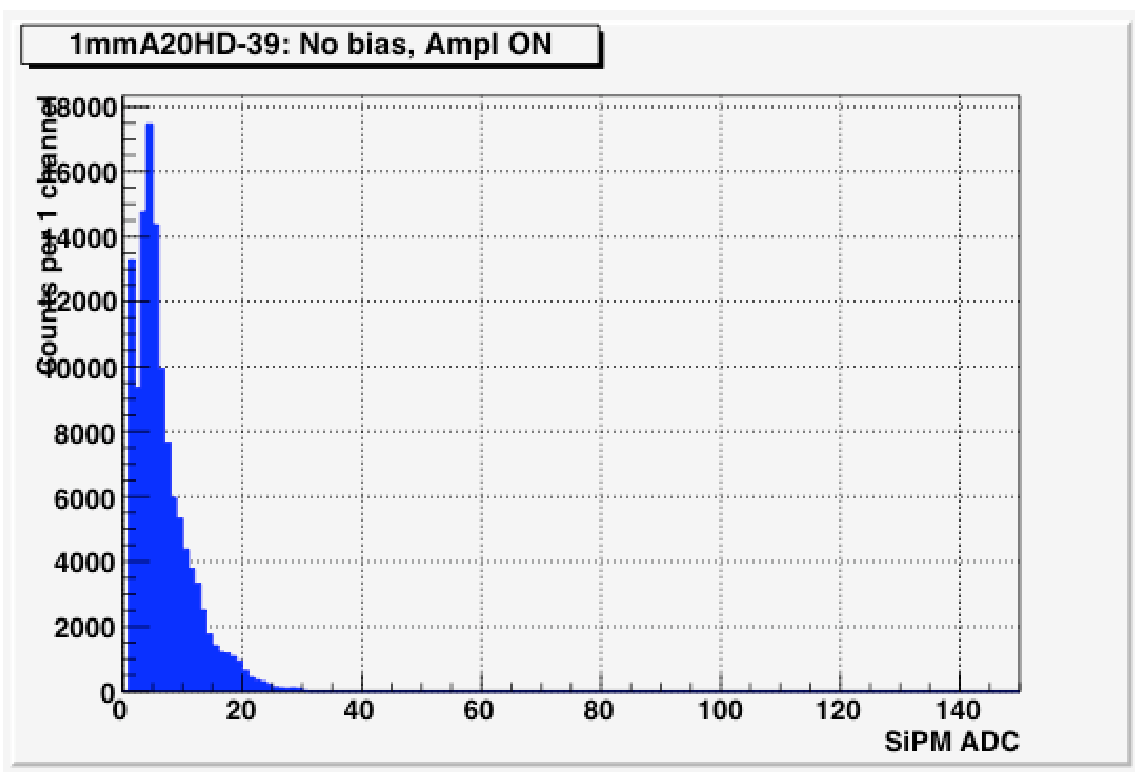
With the trigger threshold on the PMT set at 9.8 mV, a level that is above noise level but below the minimum level associated with the Sr90 source, the individual photoelectron peaks are clearly observed, as shown below. The spectra were obtained for various values of bias above breakdown, as indicated on the figures. Three spectra are shown here for +2.5 V, +3.5 V and +4.5 V, but the individual photoelectron peaks were clearly separated up to and including +5.5 V.

The "true" ADC pedestal (no input from the SiPM-preamp combination) is a sharp spike (as expected) at ADC channel ~ 8. However, with the bias on the SiPM off, but with the +5V and –5V power applied to the preamp on, the pedestal now has a width, as shown, that extends under the first photoelectron peak. This indicates the extent of the preamp-generated current integrated by the ADC. Considering that the SiPM was at room temperature and it's not trenched, its resolution is impressive. Another immediate observation is that the relative ratio of the first to second photoelectron peak is decreasing with over-bias, reflecting the increased PDE going from +2.5 V to +4.5 V.

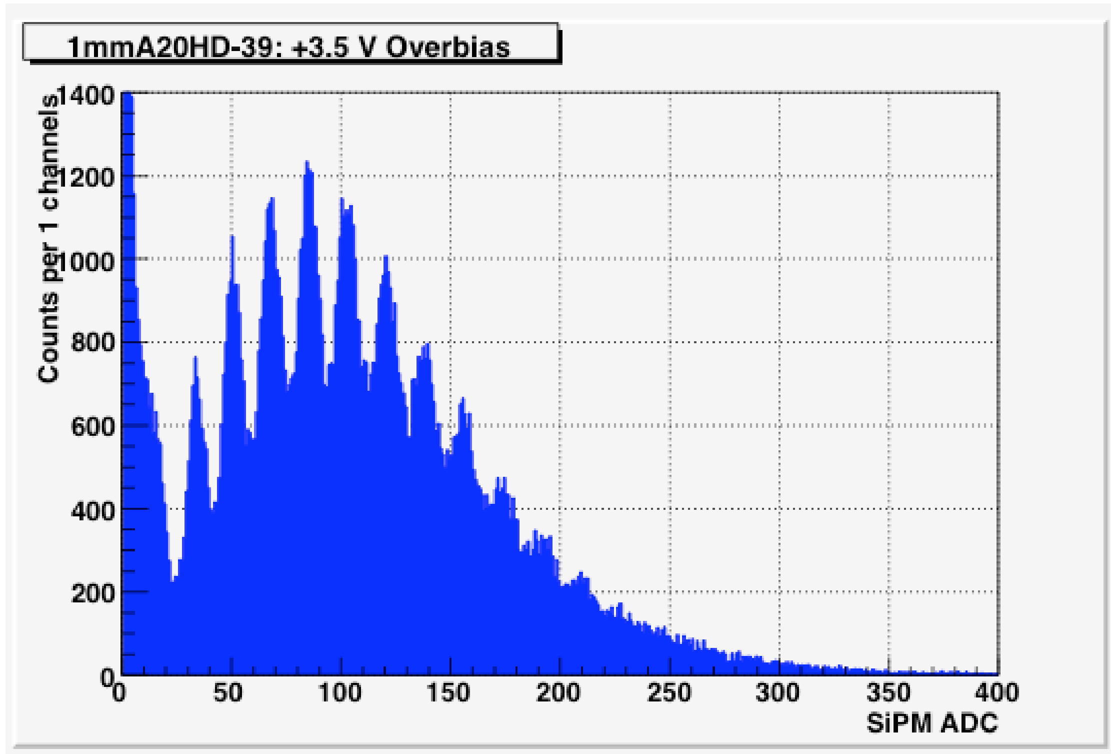

1mmA20HD-39: +2.5 V Overbias
Counts per 1 channel
SiPM ADC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
20
40
60
80
100
120
140


1mmA20HD-39: +3.5 V Overbias
Counts per 1 channel
SiPM ADC
0
500
1000
1500
2000
2500
3000
3500
4000
0
50
100
150
200
250
300



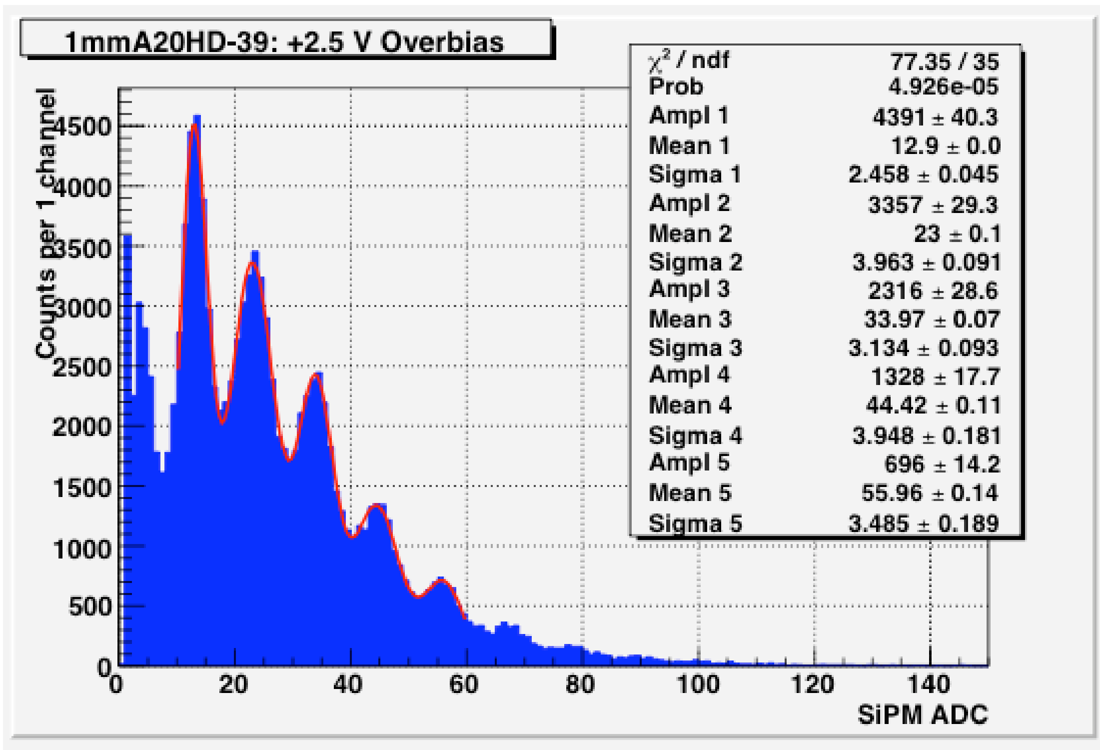


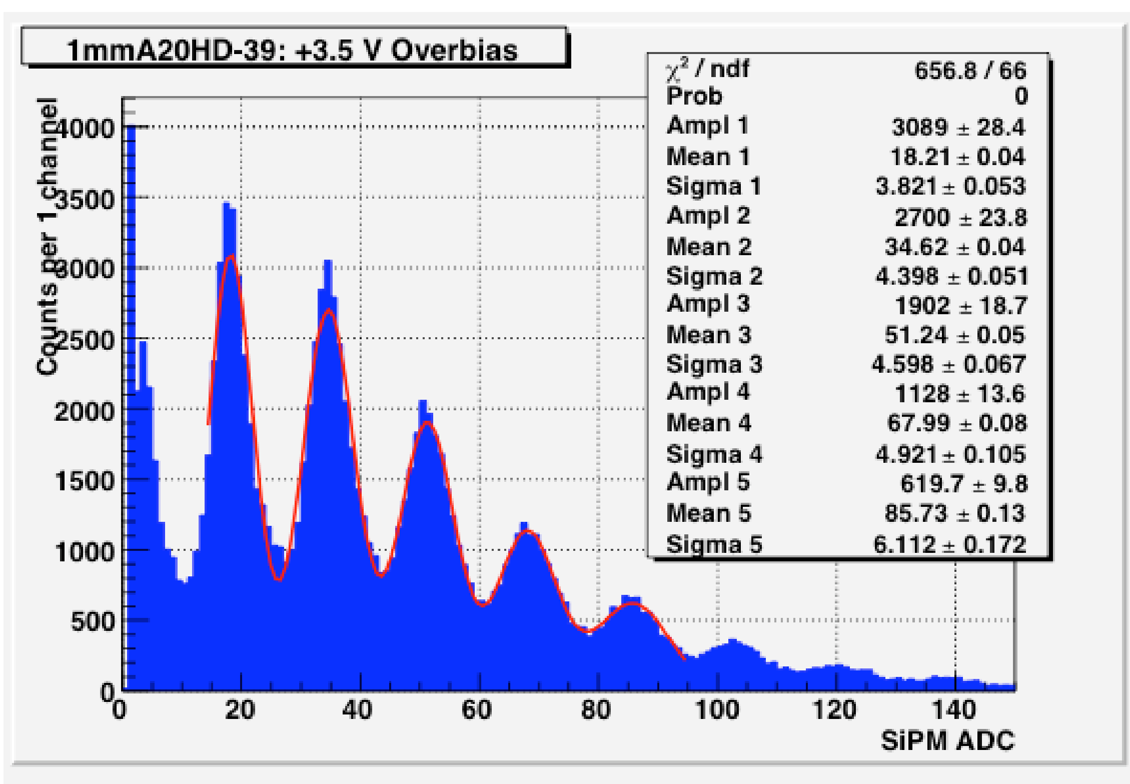
The resolution capability of the SiPM is further illustrated by the figure below that was obtained at +3.5 V but with the threshold on the PMT set at ~ 43 mV, thus now selecting events with a higher energy deposition in the SciFi. Up to 11 photoelectrons can be identified in the figure below.

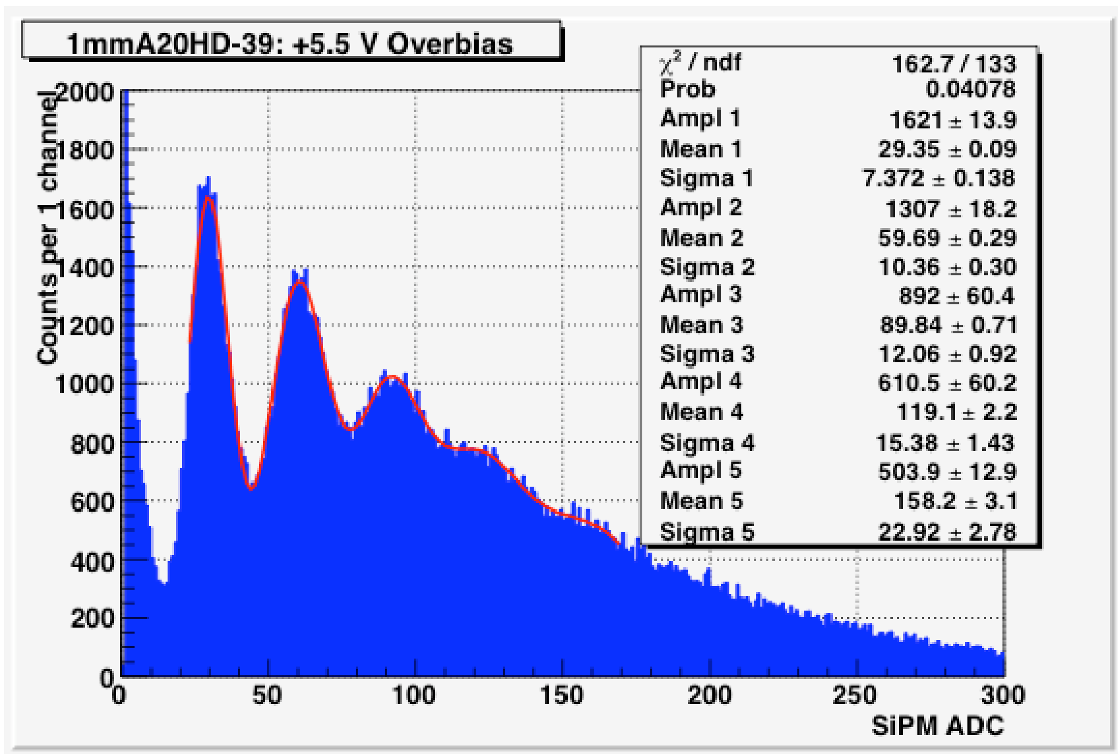


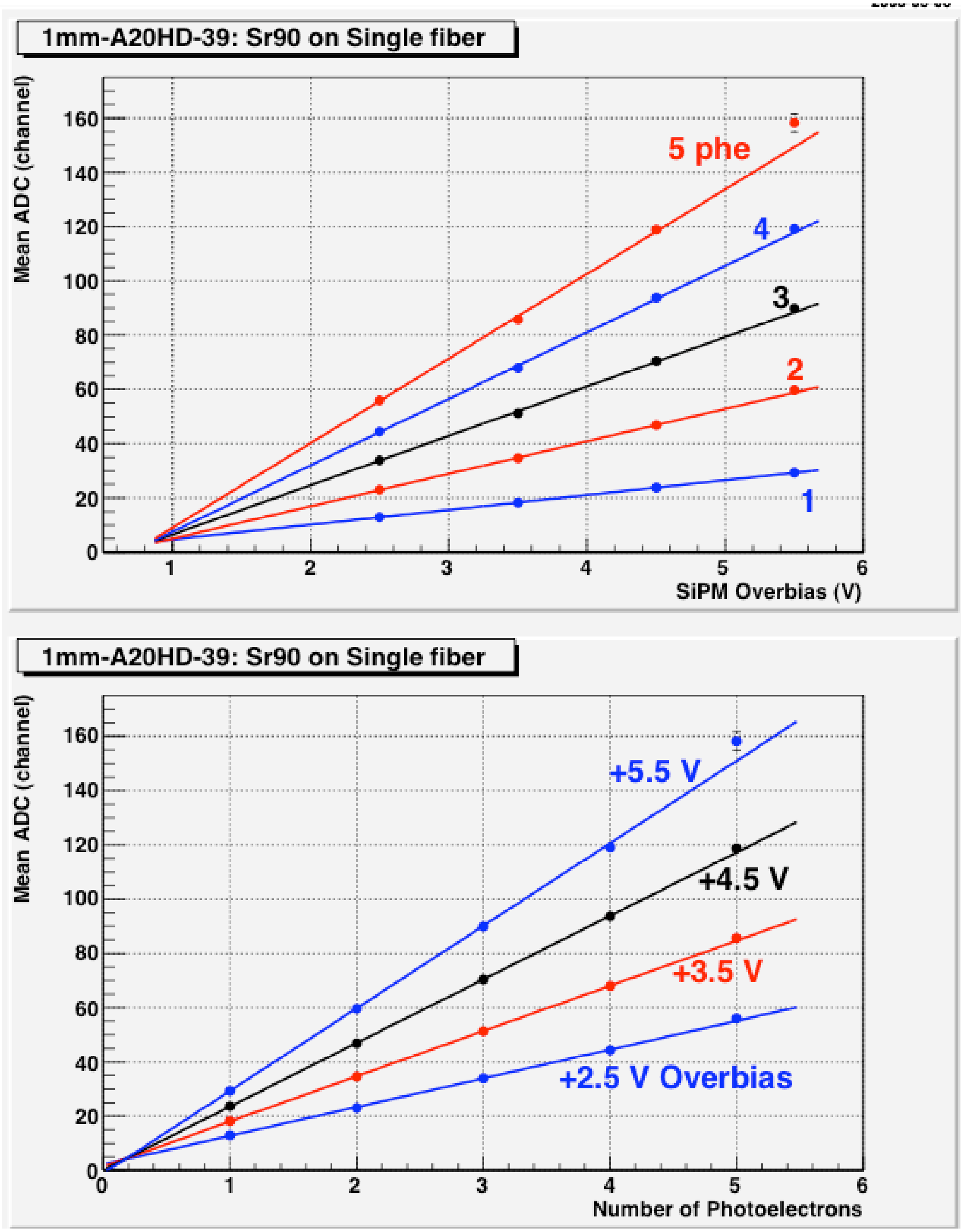
3) ***Gain and Linearity results***: Although the dynamic range in the measurements above is small, nevertheless, an extraction of linearity as a function of over-bias can be an useful diagnostic tool because the range of over-bias represents the "practical" operating range of the SiPM's in terms of PDE, gain and dark rates. The photoelectron peaks were fitted and their means extracted. The quality of the fits can be seen below for some representative spectra. Based on the peak mean values, the gain (mean ADC value) as a function of over-bias is plotted and shown below for all values of the number of photoelectrons 1-5. The relationship is linear. One interesting observation is that the lines do not intercept at +0.0 V of over-bias but at a value closer to +0.85 V. This has also been reported by Carl Zorn based on his independent measurements and it may signify that the actual Geiger avalanche occurs at some bias slightly above the breakdown voltage indicated by the IV-curves.

   A linear relationship is also observed for the ADC mean values as a function of the number of photoelectrons for fixed over-bias values. Finally, one can see the loss of resolution at +5.5 V, an indication of the noise that has now added to the width of the peaks, in addition to the increase of the widths due to the increasing ADC/p.e. conversion.


1mmA20HD-39: +2.5 V Overbias
χ^2 / ndf 77.35 / 35
Prob 4.926e-05
Ampl 1 4391 ± 40.3
Mean 1 12.9 ± 0.0
Sigma 1 2.458 ± 0.045
Ampl 2 3357 ± 29.3
Mean 2 23 ± 0.1
Sigma 2 3.963 ± 0.091
Ampl 3 2316 ± 28.6
Mean 3 33.97 ± 0.07
Sigma 3 3.134 ± 0.093
Ampl 4 1328 ± 17.7
Mean 4 44.42 ± 0.11
Sigma 4 3.948 ± 0.181
Ampl 5 696 ± 14.2
Mean 5 55.96 ± 0.14
Sigma 5 3.485 ± 0.189
Counts per 1 channel
SiPM ADC

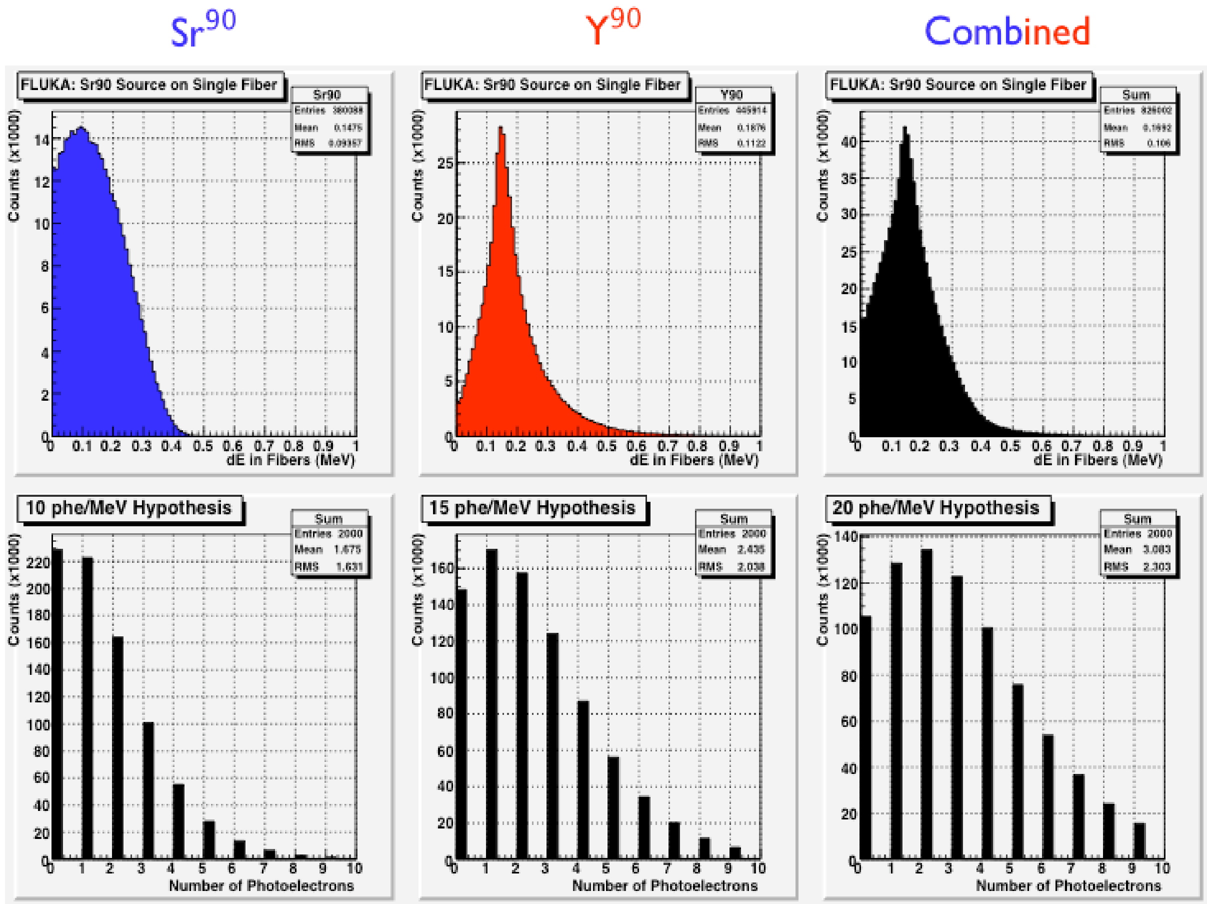

1mmA20HD-39: +3.5 V Overbias
χ^2 / ndf 656.8 / 66
Prob 0
Ampl 1 3089 ± 28.4
Mean 1 18.21 ± 0.04
Sigma 1 3.821 ± 0.053
Ampl 2 2700 ± 23.8
Mean 2 34.62 ± 0.04
Sigma 2 4.398 ± 0.051
Ampl 3 1902 ± 18.7
Mean 3 51.24 ± 0.05
Sigma 3 4.598 ± 0.067
Ampl 4 1128 ± 13.6
Mean 4 67.99 ± 0.08
Sigma 4 4.921 ± 0.105
Ampl 5 619.7 ± 9.8
Mean 5 85.73 ± 0.13
Sigma 5 6.112 ± 0.172
Counts per 1 channel
SiPM ADC


1mmA20HD-39: +5.5 V Overbias
Counts per 1 channel
SiPM ADC
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
50
100
150
200
250
300
χ² / ndf 162.7 / 133
Prob 0.04078
Ampl 1 1621 ± 13.9
Mean 1 29.35 ± 0.09
Sigma 1 7.372 ± 0.138
Ampl 2 1307 ± 18.2
Mean 2 59.69 ± 0.29
Sigma 2 10.36 ± 0.30
Ampl 3 892 ± 60.4
Mean 3 89.84 ± 0.71
Sigma 3 12.06 ± 0.92
Ampl 4 610.5 ± 60.2
Mean 4 119.1 ± 2.2
Sigma 4 15.38 ± 1.43
Ampl 5 503.9 ± 12.9
Mean 5 158.2 ± 3.1
Sigma 5 22.92 ± 2.78



4) ***Some Early Observations on the Number of Photoelectrons***: The energy deposition by the electrons originating from the Sr90 source depends on the energy spectrum from the Sr90 decay and that of the daughters and on the path the electrons take in the 1 mm ∅ fiber. The energy loss - for the configuration

used in the measurements in this report – has been simulated using FLUKA 2006.36 and the results are shown below:



The mean energy deposition in the BCF-20 fiber is 0.15 MeV, as shown in the combined spectrum of the individual Sr90 and Y90 energy spectra. The number of photoelectrons we extracted from cosmic ray measurements - using Module 1 with PHT-0044 SciFi's and XP2020 PMT's – was ~ 25 pe's for ~ 5 MeV energy deposition. Correcting for attenuation length [exp (-200/350)] gives rise to ~ 9 pe/MeV at the source of ionization (equivalent). The photoelectron spectrum observed using the Sr90 source in this report is representative of an approximately 15 pe/MeV distribution, as shown above. Of course, one has to also consider the collection efficiency of the BCAL in the cosmic ray tests but, in the same light, one has to consider the transmission efficiency of the light from the SciFi to the 1 mm x 1 mm A20HD SiPM and the alignment of the fiber to the active area of the SiPM. The exercise above is a rough check of the numbers obtained and to establish that the BCF-20/A20HD combination results in number of photoelectrons comparable to the PHT-0044/XP2020 combination.

5) ***Planning for Upcoming Tests***: As this is written, our DAQ is occupied by the cosmic ray testing of Module 2 read out by the SiPMPlus array we received from SensL, a version between Phase 1 and II. The cosmic ray testing is mandated by our obligation to provide a final report on SiPM array performance using cosmic rays. The latter take time to accumulate meaningful statistics to extract the number of photoelectrons. With the DAQ occupied thus, we are using the time to improve the measurements of the A20HD and A35HD SiPM's we have available. A collimator for the Sr90 source will be made securing the fiber relative to a 0.5 mm ∅ collimating hole centered above the fiber. We are also designing jigs to mount and align the BCF-20 SciFi to the TO46 and TO5 housings (cans) for the 1 mm and 3 mm SiPM's, respectively. SensL quotes the accuracy of placement of the SiPM within its housing as 0.3 mm. Our own measurements, using a traveling microscope, produced a maximum variation of 0.2 mm of the relative position of the SiPM active area with respect to the inside edge of the can. Such position variations, considering the size of the fiber and the 1 mm SiPM, make measurements of number of photoelectrons generated somewhat unreliable. However, for the 3 mm version, the determination of the actual number of photoelectrons - based on SciFi and Sr90 measurements - will be much more reliable.

   Using the calibrated 2" PMT's, we will determine the number of photons delivered by the single BCF-20 fiber to each end, therefore the PDE of the 3 mm SiPM's can be determined. The same will be done for Module 2 using cosmic rays. This will allow us to work with SiPM's using the single BCF-20 fiber and with SiPMPlus arrays using both the single fiber technique with Sr90 source and Module 2 using cosmic rays. Measurements with the single BCF-20 fiber and Sr90 source proceed very fast, however, cosmic ray testing takes at least a week per measurement. We will apply to NSERC in the fall for a modest equipment grant to allow us to instrument an additional DAQ so two independent measurements can take place in parallel. In the meantime we proceed as fast as the DAQ availability allows us.

   Further reports on updated results will follow.