What Did We Learn from PMT-Bo First Fill?

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1) *Quick review of setup and Filling*

1.i : Internal components:

Bo was set up with one working prototype PMT in the lower mount (PMT 2) and a mechanical model in the upper. PMT2 has a real TPB plate, made in lab 6 according to the MicroBooNE recipe a few days before filling and kept covered by a black sheet. PMT1 (mech model) has a blank acrylic plate.

The working PMT was connected to the SHV feedthrough in port 2 by a Teflon sheathed SHV cable as will be used in MicroBooNE.

Four fibers descend from a feedthrough flange and are fixed to specially fabricated fiber mounts which hold them in place pointing in the following directions:

i) VIS1 : Directly at PMT1 photocathode from approx. 2mm away
ii) VIS2 : Directly at PMT2 photocathode from approx. 2mm away
iii) UV1 : Pointing at TPB plate 1 from beside plate 2
iv) UV2 : Pointing at TPB plate 2 from beside plate 1

1.ii External components:

The SHV from feedthrough port 2 is connected to a splitter box, which is supplied with 1000V HV. The signal cable runs to a Tektronix TDS5054B scope.

Two visible LEDs are pulsed using a Fermilab-built pulser board, controlled by a macbook pro. The pulser has LEMO outputs which connect to “postage stamp” mountings for up to four LEDs, labeled 0 to 3. For the tests described here, a pulse sequence generated by a root script available in the uboone electronic logbook is used. This sequence corresponds to alternate firing of LED 0+1 and then LED 2+3 approximately 300Hz for 2 seconds, followed by a 2 second break. The LED bias voltage is set in the pulse sequence definition and can be modified interactively when running. Each LED pulse corresponds to an approx. 3V spike being delivered for 10ns above the constant DC bias. A functional pulse sequence has the LED voltage being pushed from below to above threshold by the spike.

The two visible LEDs are labeled 1 and 2, and are mounted in home-made mounts with screw-in optical fiber connections. Commercial fibers run from the LED mount to fiber feedthrough where they can be attached to any of UV1, UV2, VIS1, VIS2. Any fiber port unused is covered by a tyvec cap.

2) Filling Report + Argon Boiloff Rate

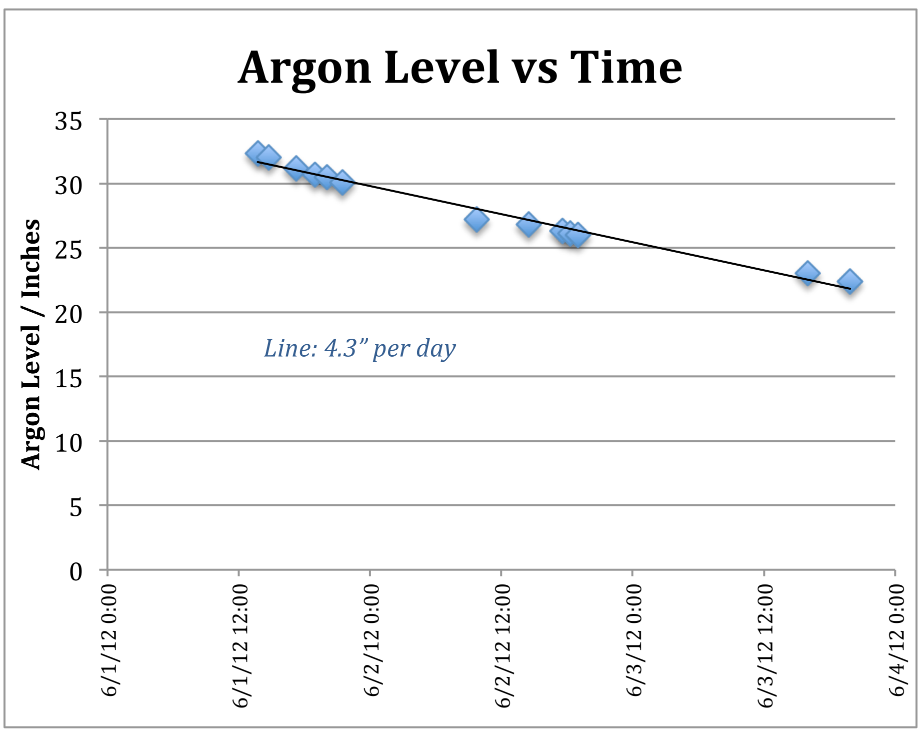
The filling procedure for Bo, starting from an open cryostat, involves the following:

1) Lift instrumented lid into cryostat and configure cryogenics for filling (regenerate filters, etc)
2) Evacuate cryostat with vacuum pumps for ~1 day
3) Cool filling line
4) Commence filling

This time the procedure took approximately 3 days, but this was both shortened and lengthened by the fact that some equipment was already prepared and / or in use for Luke filling.

The argon level is recorded by a capacitive level monitor, which is pre-calibrated and read out electronically. The filling took place in 2 stages, and the level reached was 37". Due to the segmented filling procedure and some preliminary tests, PMT2 had been immersed in argon for approximately 36 hours before any of the measurements reported in this document were made.

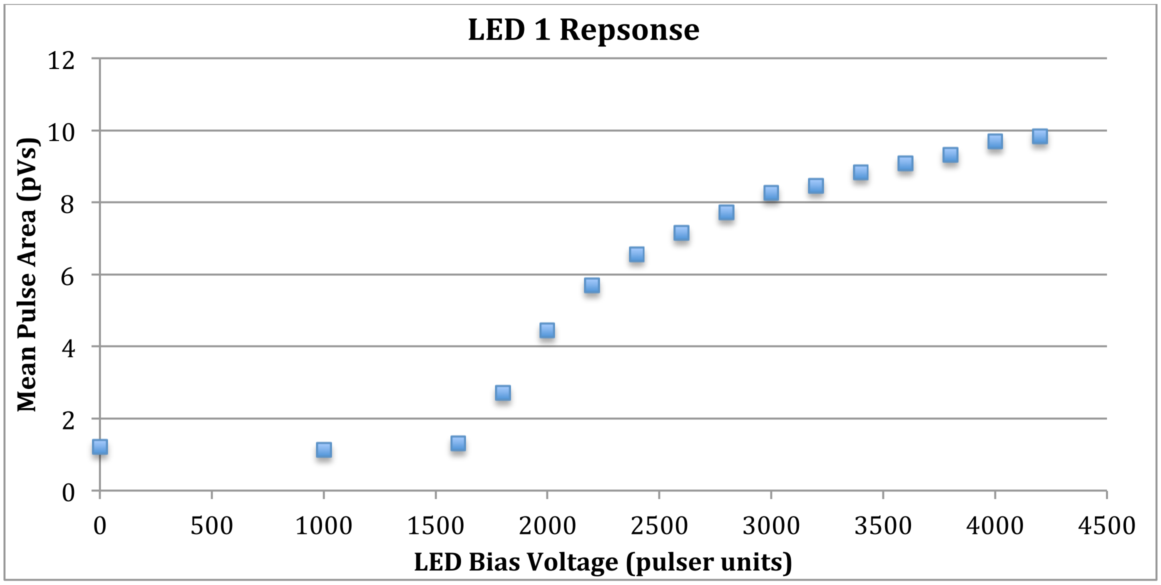
Action item: Whilst we think the level monitor is calibrated, we don't know at what height each of our components sit. Next time we open, we need to measure the vertical positions of all important pieces, in particular PMTs, fibers and bases, relative to the bottom of the purity monitor.



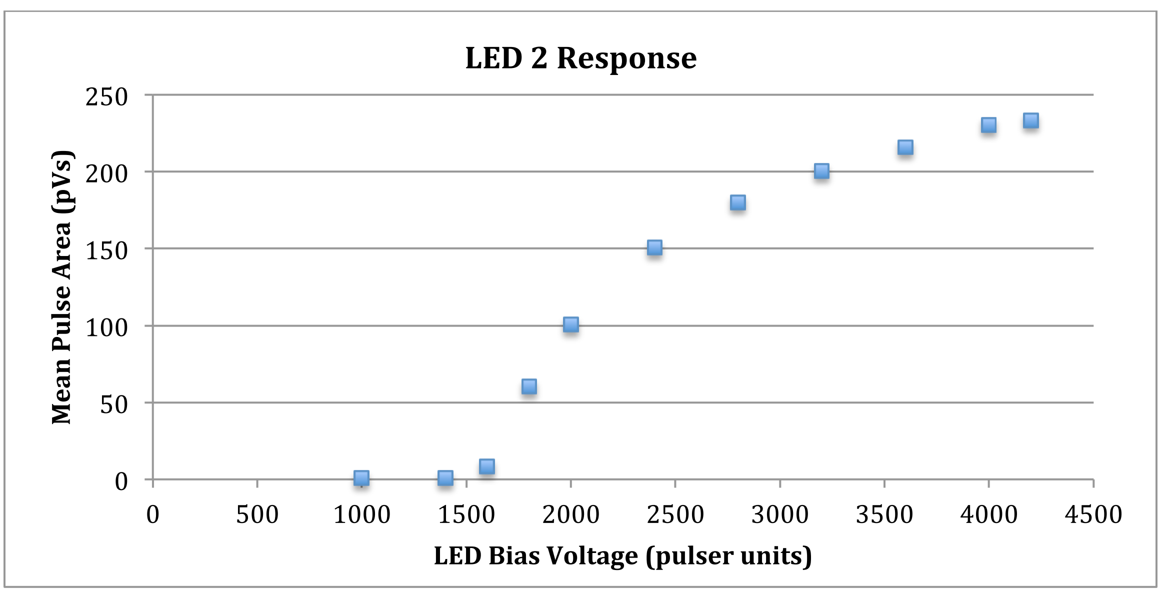
The time dependence of the argon level fits neither a linear nor exponential curve perfectly, but after an initial steep drop the rate of argon loss settles down to approximately 4" per day. The radius of Bo is 22", and so operating with no condenser or extra heat shielding, we can expect to use ~24 liters of argon per day. The current plan is to install extra heat shielding ("baffles") before long term running begins, and a condenser may or may not arrive mid summer.

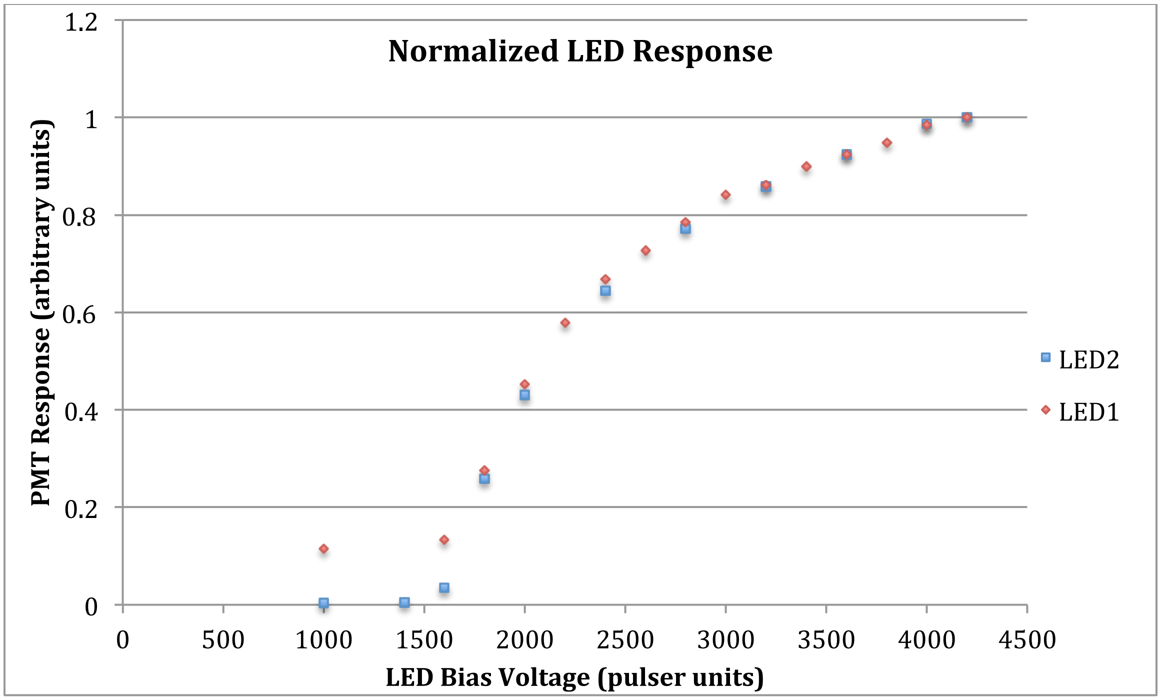
3) LED Characterization

The pulser board was configured according to the fast pulse sequence, available on the elog. Fiber 2 was used to connect LED1 to VIS2, and the DC bias voltage for the LED was scanned. The PMT signal was read out using the scope in histogramming mode, and the mean pulse area was recorded at each voltage. This response is shown below.

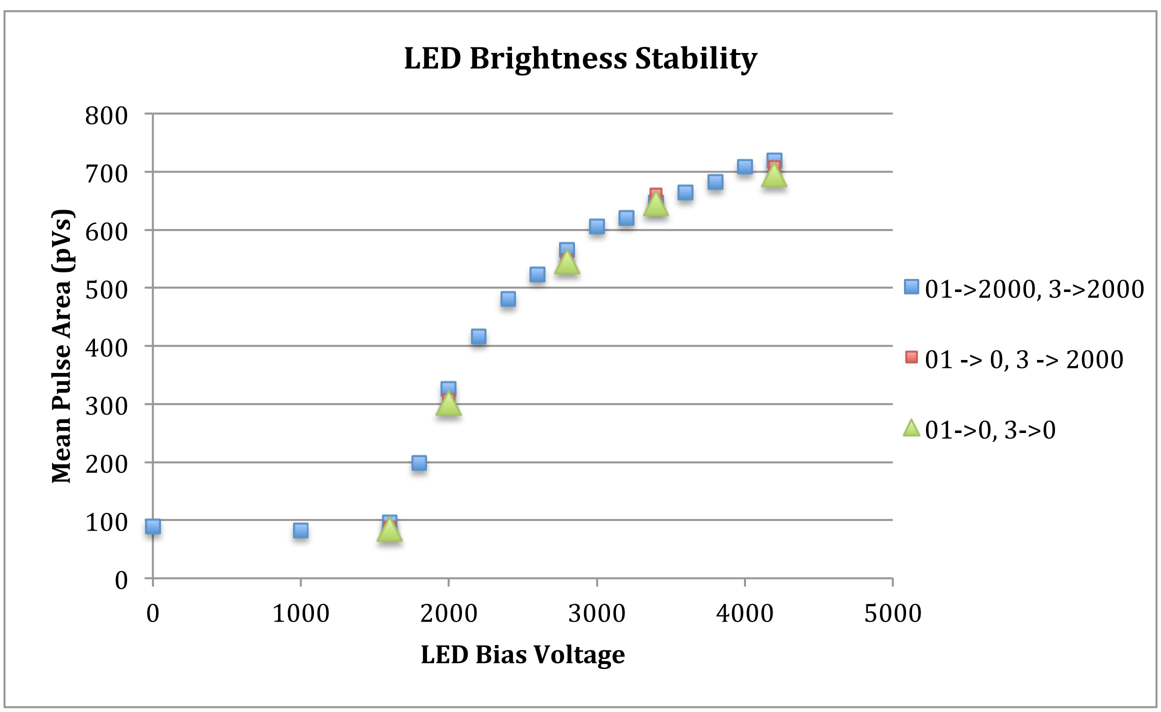


The procedure was repeated for LED2. The threshold and general behaviour are very similar, but the brightness of LED2 appears much higher. Given how perfectly the shapes overlap when normalized to one another, it seems sensible to attribute this difference to the alignment and installation of each LED in its mounting, rather than to different behaviour in the LED itself.



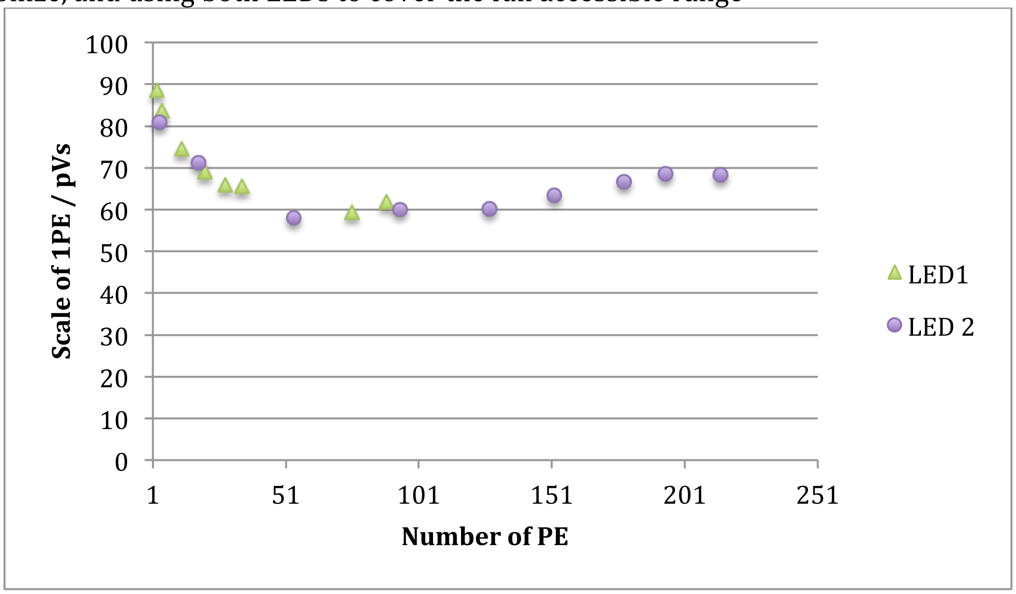


The response for LED1 was remeasured (at a coarser granularity) with other pulser channels pulsing at different voltages, but no extra LEDs connected. We find no effect on the response in this case, so the pulser output voltage is stable with respect to pulsing an absent LED (in contrast to the big discrepancies which are observed when pulsing another connected LED). These measurements were also separated in time by approximately one hour each, so this also gives us an idea of the stability of the system on this timescale.

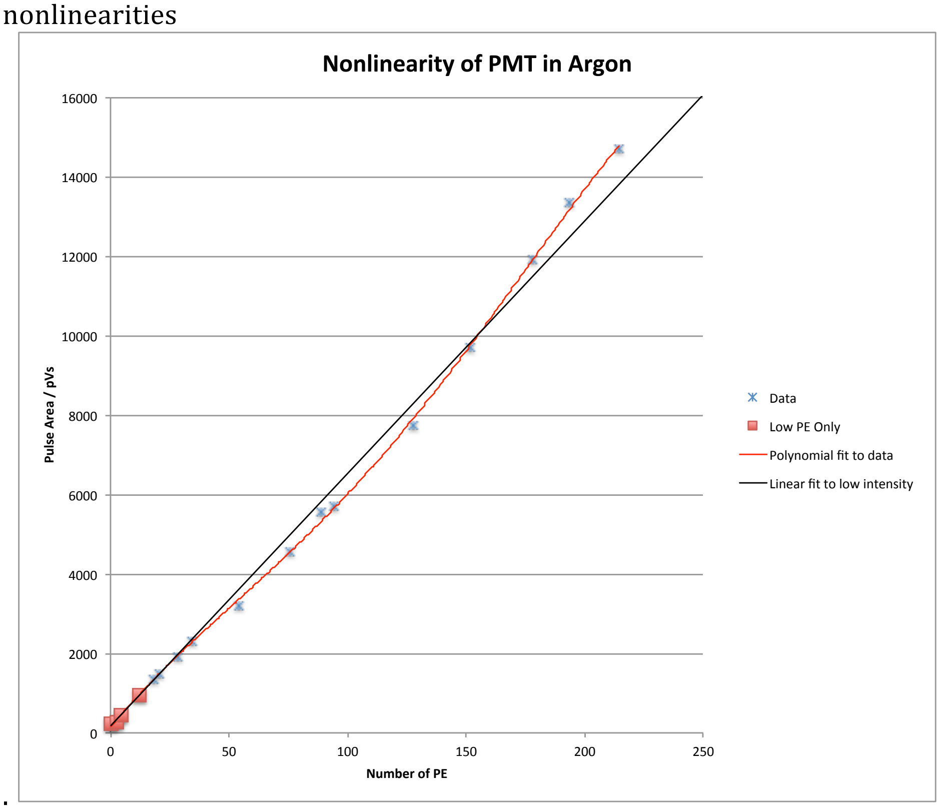


4) PMT 1PE and Gain Determination, and Stability

The 1PE scale can be extracted from the shape of the pulse-area histogram assuming poisson statistics. This method is appropriate in the >5.p.e. range. The 1PE scale for the LED bias scan shown above is given below, measured after the PMT has had ~3 days to stabilize, and using both LEDs to cover the full accessible range



This is shown explicitly as a linearity curve below. We show both the extrapolated linear behaviour from the low PE regime and a polynomial fit to the data taken which incorporates nonlinearities



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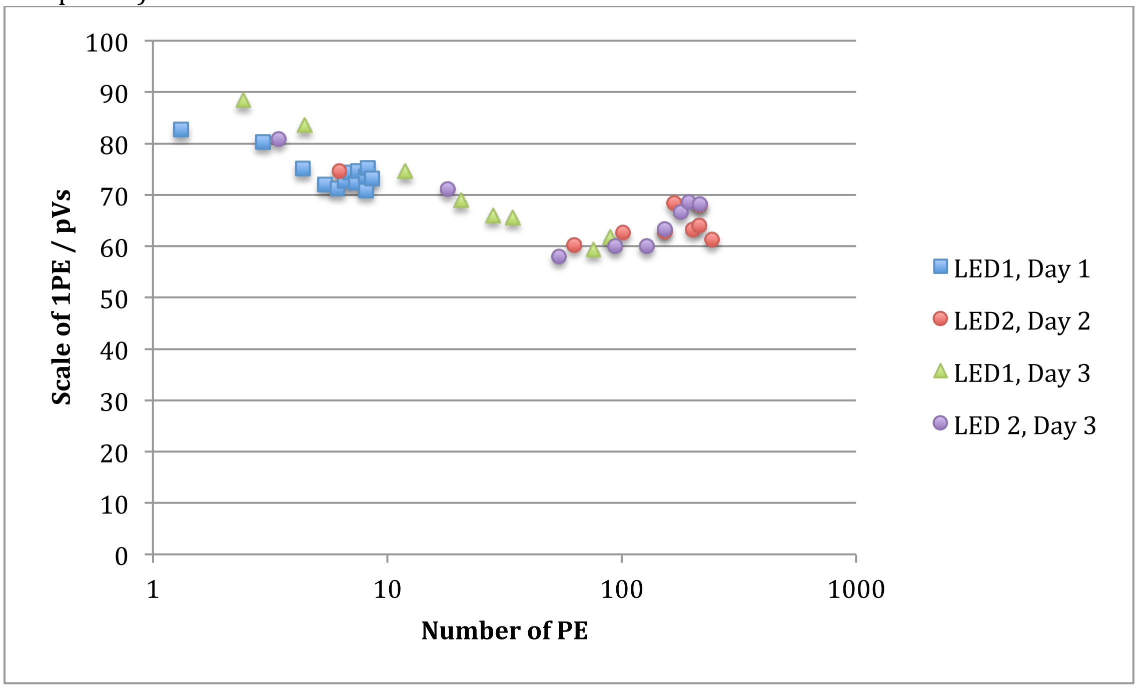
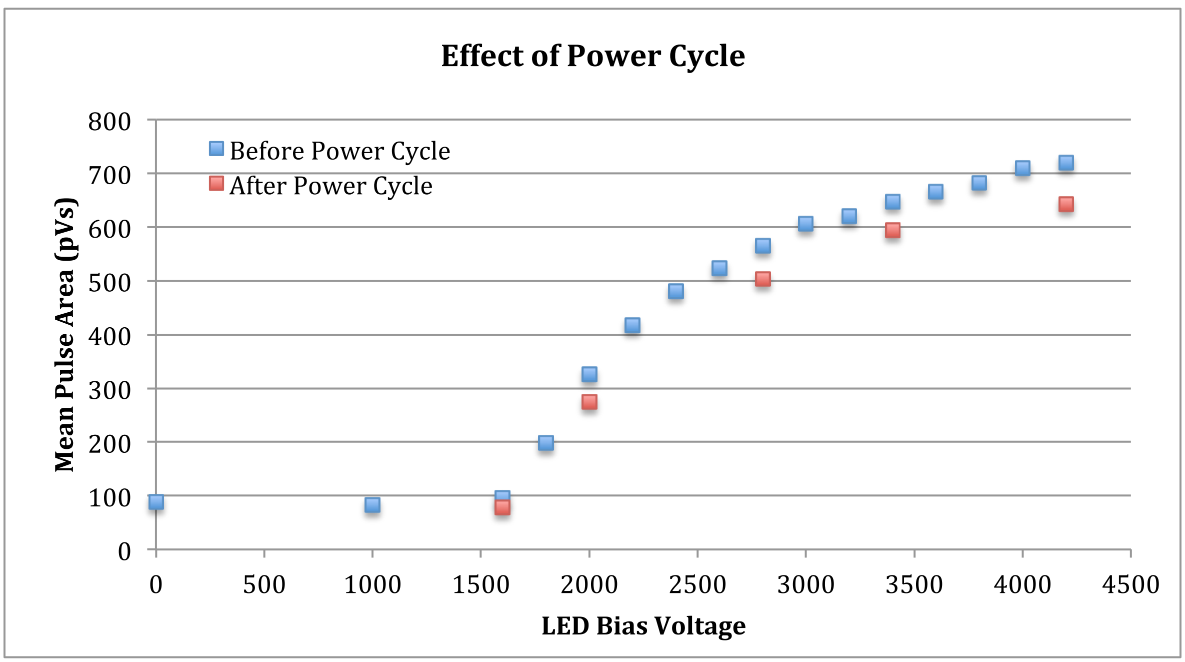
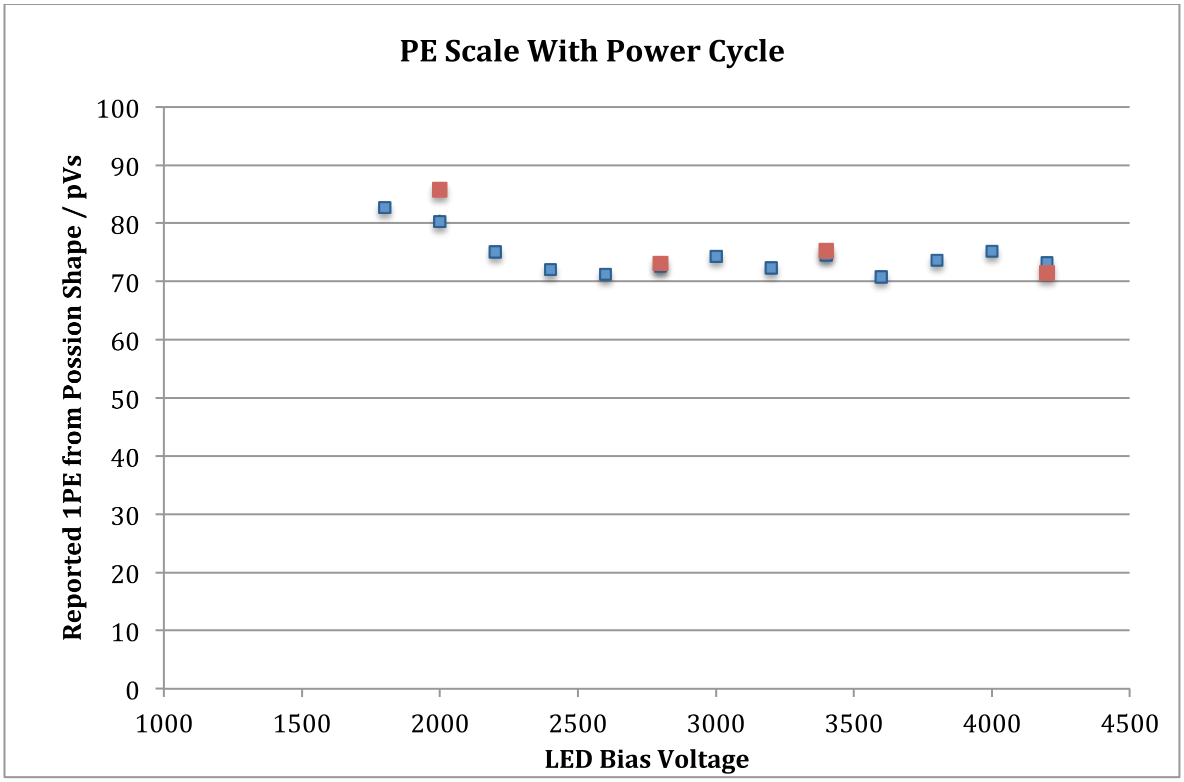
To get an idea of how much 1PE drifts, we can compare the 1PE values determined here with those from the LED intensity tests taken on day 1 (on a log PE scale to show low and high PE points)

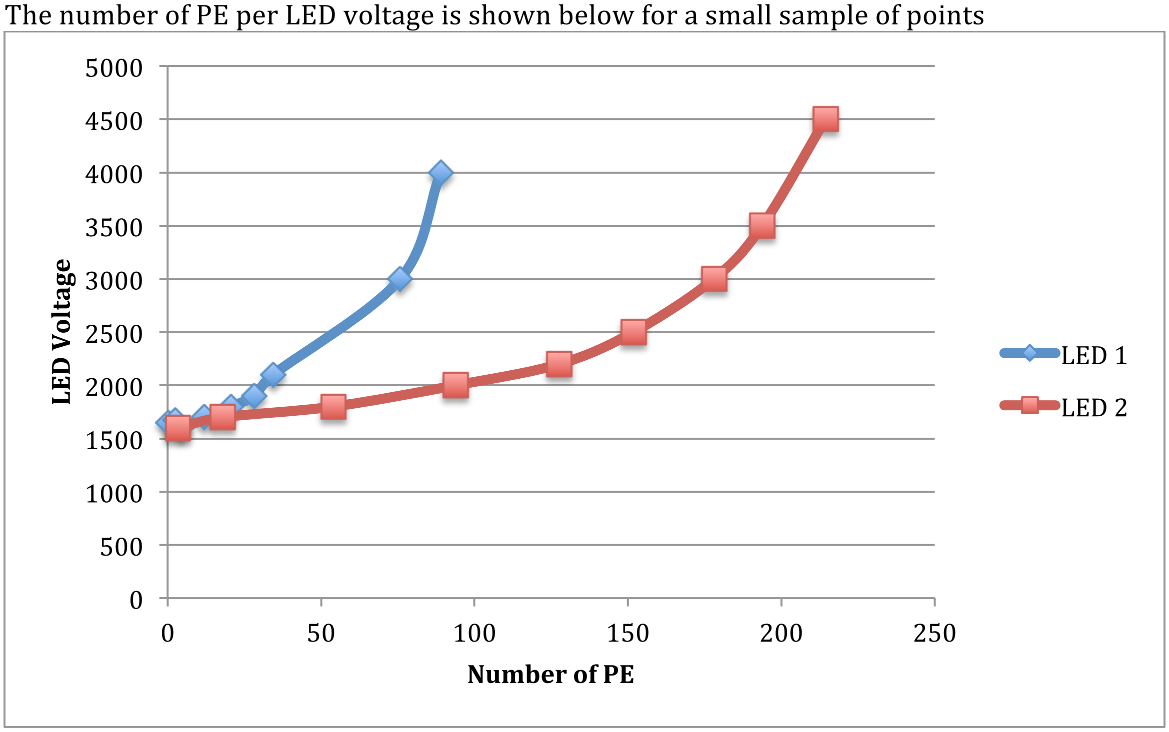


The effect of a power cycle (switch off all equipment including HV, leave 1 hour, switch back on and allow to settle for ~30 mins) was tested and is shown below.



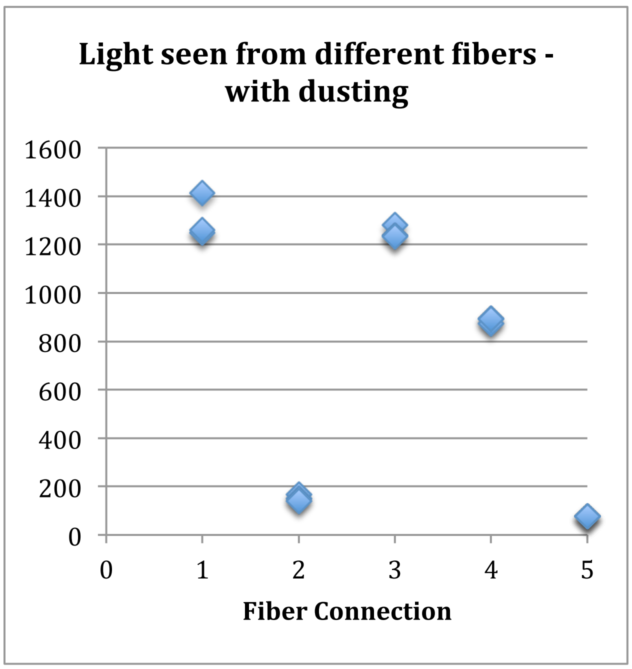


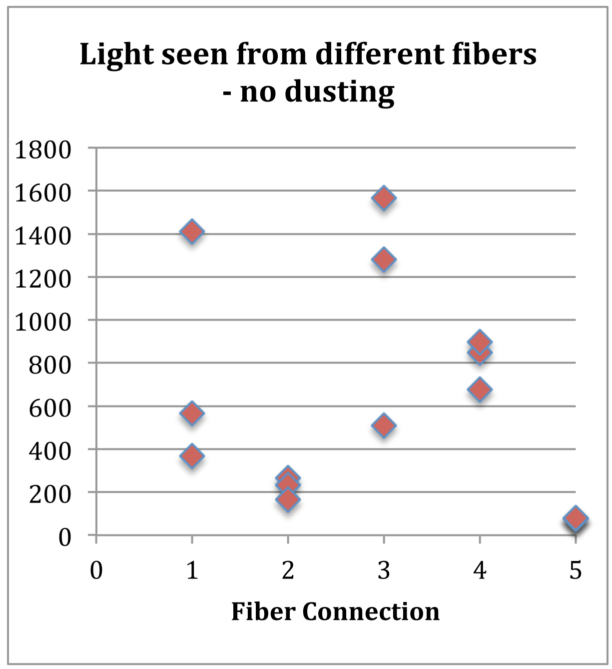
The number of PE per LED voltage is shown below for a small sample of points

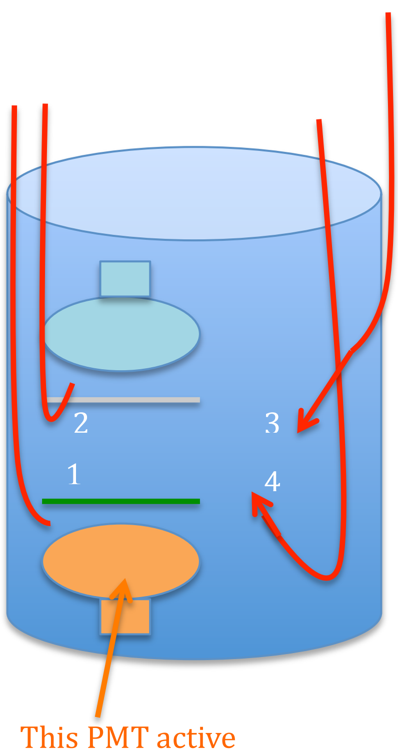


5) Visibility of light from Each Fiber by PMT 2

LED1 was connected to fiber 2, and the pulser set to pulse on the fast pulse sequence with a bias of 2800. The fiber was connected to each feedthrough without changing the LED1 configuration of connection. At first the process was very unrepeatable, with results varying wildly between repetitions. However, much of this variation turned out to be due to dust which had settled in the fiber feedthroughs. After a blast with a compressed air duster, a much better stability was achieved. The light visibility at each fiber is roughly what would be expected, the only possible surprise being the high visibility of the visible light from fiber UV2, through the opaque TPB plate. In the plots below, each location has 3 measurements. We should consider optically shielding each plate from the oposite UV fiber, since there is a high light visibility to this fiber.





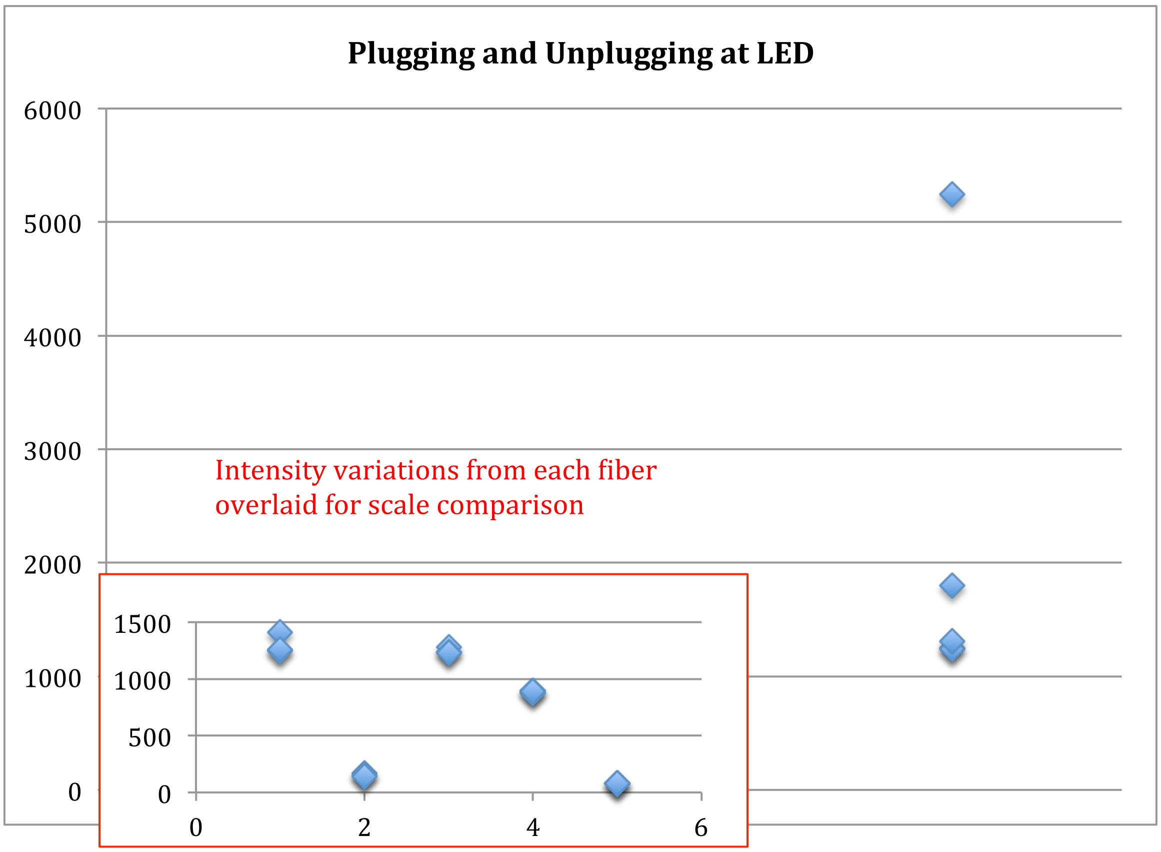


1: VIS2
2: VIS1
3: UV2
4: UV1
5: No Fiber Connected (dark rate)

6. Flaky Fiber Connection Issues

After dusting the fiber connections at the feed through are more reliable – but the presence of occaisional large outliers due to a poor connection makes me worry about the possibility of drift on a long timescale, or instability due to being knocked, etc. However, the connection at the LED end is incredibly sensitive, and between unplugging and replugging, orders of magnitude differences in light levels can be observed.

Action item: Deal with fiber instabilities. I think fibers should definitely be glued at the LED end. To avoid major problems later I might even consider replacing the screw-down fibers with a single fiber running from PMT to LED, fixed permanently.



This feature means that it is impossible to make meaningful comparisons between LEDs or between fibers (between anything that involves disconnecting and reconnecting an LED) and is a major concern for long term stability.

7) Hunting Down Light Leaks

2 major light leaks found : fiber feedthrough to purity monitor was bare, and another fiber feedthrough which has an unknown function.

Initially fixed up with black tape, but now I have black plastic caps which give a much more light tight solution. Now in one dark rate run, typically 0 or 1 pulse in integration window. Scope reads pedestal value of 80pVs.

Fiber feedthrough housing for our fibers, and all other flanges seem light tight. However, at the LED end of fiber there are light leaks. Patched up with more tape for now, but needs re-taping now and again after being handled. Hopefully we can come up with a better mount which is both more stable and more light tight eventually.

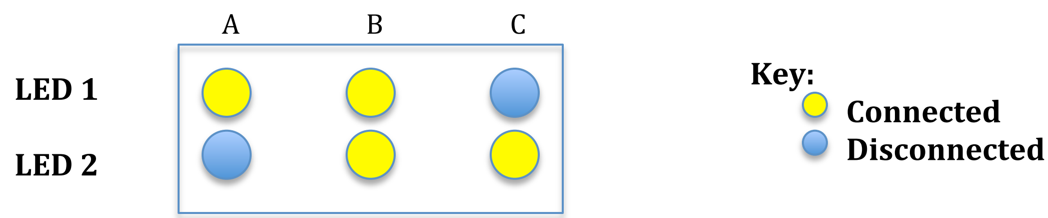
Action Item : Find a better way to light tight the LED housing

8. PMT Linearity Study Using 2 LEDs

Two LEDs were set pulsing connected to channels 2 and 3 of the pulser, which are programmed to light simultaneously. The following procedure can be used to test the linearity of the PMT response, independently of fiber connection and pulser configuration effects:

1) Choose a pulser configuration delivering desired voltages to LED1 and LED2
2) Connect LED1 fiber to VIS2 (A)
3) Record pulse spectrum with LED1 connected to VIS1 only
4) Connect LED2 fiber to UV2 (B)
5) Record pulse spectrum with both LED1 and LED2
6) Remove LED1 fiber from VIS2 (C)
7) Record pulse spectrum with LED2 only
8) Change voltage on LED1 if desired, and repeat

In this way, a range of voltages on VIS1 and VIS2 can be scanned, and a measurement of PMT linearity made which is not sensitive to systematics associated with fiber re-connections or voltage changes of the pulser.



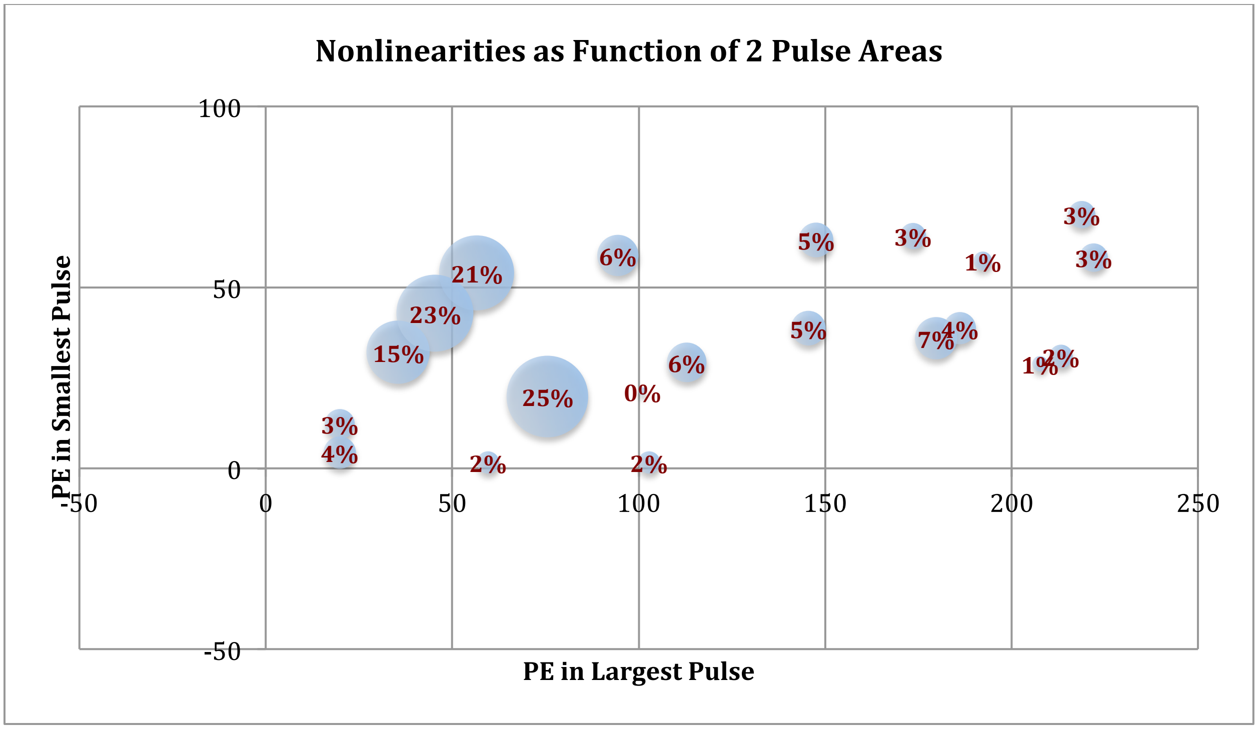
For a particular run, the bias voltage setting on LED2 is held fixed. The voltage on LED1 is varied. When the voltage setting on LED2 is changed, however, the voltage on UV2 also changes – this is an unpleasant feature of this pulser. Whilst we can still make a perfectly good linearity measurement in this situation, we don't have as finer control over how we scan the space of pulse shapes as we would if we could control both independently. As such we must measure both the pulse area for the "fixed" and "varying" LEDs each time.

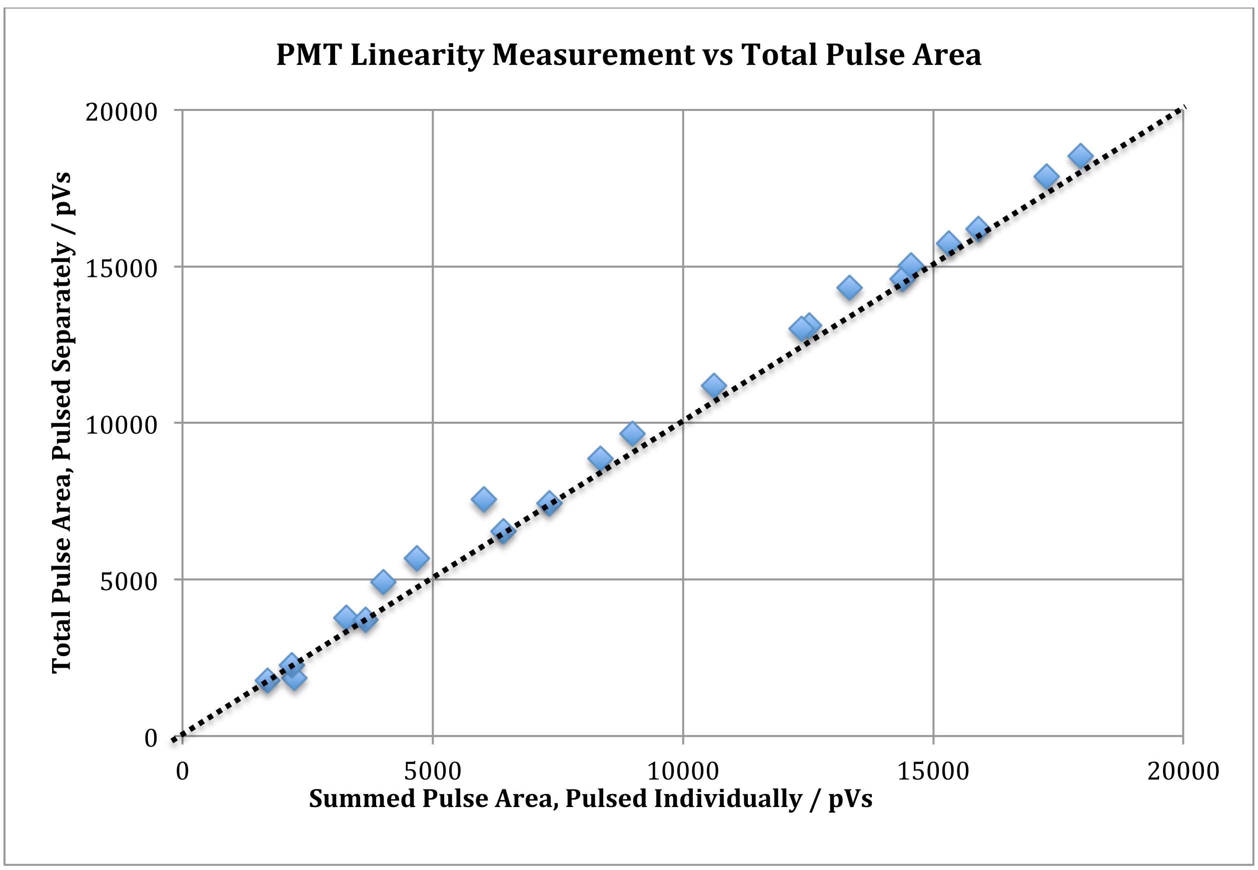
If the PMT is linear, the average pulse area from UV2+VIS2 connected should be the sum of the average area from VIS2 plus the average area from UV2, so long as we hold the pulsing pattern fixed between measurements.

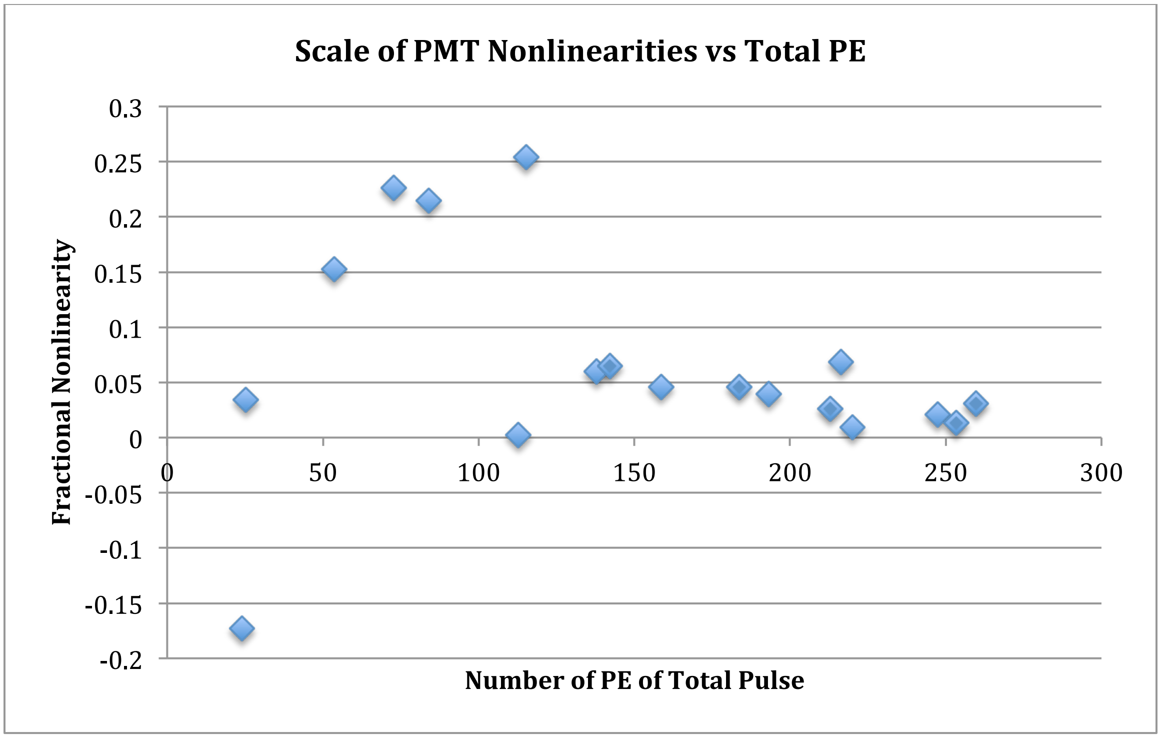
The dark rate must be accounted for, or a small offset is observed. The dark rate is easily measured with no fibers connected, and subtracted.

Since the brightness of both LEDs changes when only one bias is adjusted, it is not trivial to find the expected form of the nonlinearities – in fact it is some function in 2D space, of the area of pulse 1 and the area of pulse 2. The bubble plot below, where the area of one bubble represents the fractional nonlinearity is the best I can come up with. Simplified plots which have some information discarded, and are nontrivial to interpret, also follow.

We see that large nonlinearities of up to 23% are observed in the region of intermediate size pulses (20PE both). For both pulses small or both pulses large, much less linearity is observed. In the next run, this measurement could be repeated with a much finer graining to map the space more effectively.


Nonlinearities as Function of 2 Pulse Areas
PE in Smallest Pulse
PE in Largest Pulse
100
50
0
-50
-50
0
50
100
150
200
250
3%
4%
15%
23%
21%
25%
2%
6%
0%
2%
6%
5%
5%
3%
7%
4%
1%
1%
2%
3%
3%


PMT Linearity Measurement vs Total Pulse Area
Total Pulse Area, Pulsed Separately / pVs
Summed Pulse Area, Pulsed Individually / pVs
20000
15000
10000
5000
0
0
5000
10000
15000
20000



Scale of PMT Nonlinearities vs Total PE
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
50
100
150
200
250
300
Fractional Nonlinearity
Number of PE of Total Pulse

9) Moving Forward / Action Items

The good news is that all components of this system work to first order. The PMT seems reasonably stable and we know how to pulse the LEDs and read out data using the scope.

We still need to mount and test UV LEDs, but a critical component is missing, and it is not possible to make a good optical coupling without it. Hopefully it will arrive soon, and can be tested in Bo either filled, or evacuated – good running of the PMT has been demonstrated in both cases this week.

One goal to move forward is to automate the data taking process. The pulser board and scope can both be controlled remotely by the DAQ server, which was installed by Eric on Friday. I plan to start working on this in the near future.

We should think about other strategies for fiber connections at the LED end, as this connection is weakest point of our current setup in many ways. I have concerns about both nonreproducibility of LED configurations and gradual drift during a long run, and maybe a single fiber running from mount to a glued spot on the LED will save us a lot of trouble down the line.

The cosmic trigger needs to be set up – this will be Christie's job and should be a nice first task for her summer.

Next fill I hope we can look at scintillation light from cosmics and the pulsing UV LEDs, perhaps with a more automated data taking setup. Electronics arrive from Nevis June 20, and we are ready and willing to install.