A Study of the Fine Mesh Photomultiplier Tube Assemblies H6152-01 and H6614-01

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1 Overview

Two fine mesh photomultiplier-tube (PMT) assemblies from Hamamatsu: H6152-01 and H6614-01 have been studied with regards to their timing capabilities and their behavior in magnetic fields up to 1.2 T. A fast blue LED pulser has been used as a light source for both measurements. The goal of the studies was to investigate the suitabilities of these PMTs as a readout system for the outer layers of the BCAL, the start counter and eventually the time of flight wall. These two models have later been replaced by Hamamatsu by the H6152-70 and H6614-70 models. In both cases the photo tubes are the R2459 and the R5505, respectively. One of the main changes between the models tested and the newer ones is that the newer models use positive high voltage while the older ones needed negative high voltage.

1.1 Module H6152-01

The module H6152-01 contains a R5505, 25mm tube with 15 stages and a typical gain of $5{\cdot}10^5$ at an operating voltage of 2kV. For the tube that has been tested for this report, we determined a gain of about $4{\cdot}10^7$. It is a fast tube with a rise time of 1.5 ns according to the documentation, a transit time of 5.6 ns and a transit time spread of about 0.35 ns (FWHM).

1.2 Module H6614-01

The module H6614-01 contains the R5924, 51mm tube with 19 stages and a typical gain of ${\cdot}10^7$ at an operating voltage of 2kV. For the tube that has been tested we determined a gain between $4{\cdot}10^7$ and $4.8{\cdot}10^7$. It is a fast tube with a rise time of 2.5 ns according to the documentation, a transit time of 9.5 ns and a transit time spread of about 0.44 ns (FWHM).

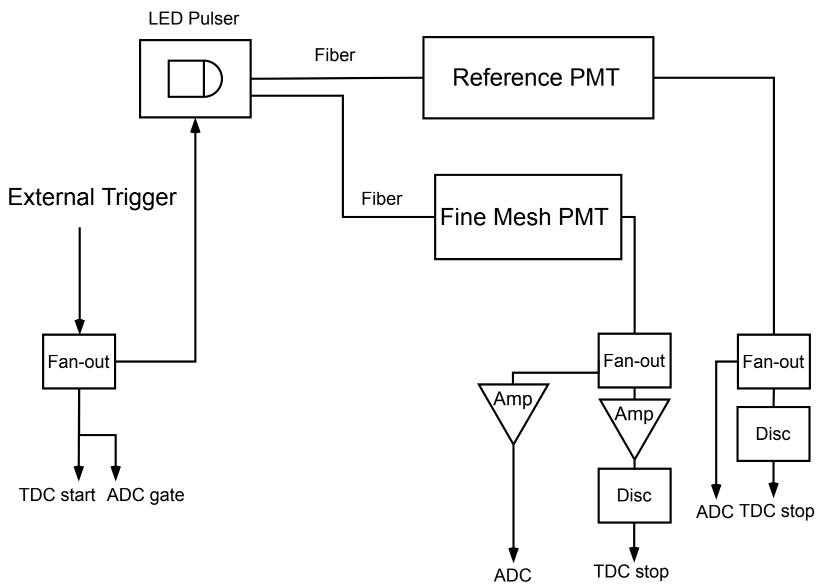

Figure 1: Setup used for timing measurements.

2 Setup for timing properties measurements

Two blue LED light sources have been used for the measurements described below. The LED's have been controlled by a design described by Kapustinsky et al. [1, 2], where a capacitor is discharged through the LED and an inductance parallel to the LED significantly reduces the signal tail. This setup was able to produce light pulses which in turn produced PMT output signals that closely resembled those produced by scintillators. The typical rise time was 2 ns and the decay time about $3-4$ ns. The light output could be varied by changing the charging voltage of the capacitor. This made it possible to study the PMT's response over a wide range in light intensity from the single photo-electron regime up to several thousand photo-electrons (PE). The setup used for timing measurements is shown schematically in figure 1. The external trigger is generated by a pulser. A linear fan-out is used to multiply the trigger signal to start the TDC's and to provide the gate signal for the ADC's. One of the pulser signals is converted to TTL and triggers the LED pulser. The light of the LED is transported by 1 mm optical plastic fibers (Edmund Optics, 1000UMX1) to the photo cathodes of the fine mesh PMT and the reference PMT. While the light output at the end of each optical fiber is not exactly identical, they are very similar. For the measurements it was not necessary that the two are the same. The PMT signals corresponding to the LED light pulse are split using linear fan-outs and amplified as necessary. For the TDC stop signals the output of a constant fraction discriminator (for the H6152-01 system) and a leading edge discriminator (for the H6614-01 system) have been used.

3 Setup for gain shift measurements

The gain as a function of background rate has been measured for the H6614 module using two LED sources that have been triggered independently. The setup used was very similar to the one shown in figure 1, except that no reference tube has been used and a second fiber, connected to the background light source has been added. The amplitude of the background light has been set such that it corresponded to about 180 PE per pulse. The other light output has been set to about the same amount. The background light pulse had a typical width of $30 - 40$ ns since the LED was directly driven by the amplified pulser signal. The rate was varied from 1kHz up to 300kHz. At the highest rate the anode current approached the recommended maximal anode current for the PMT.

4 Results

The single photo-electron spectra and timing capabilities of both modules have initially been tested at FIU without the presence of a magnetic field. These measurements have then been repeated using the setup at Jefferson Lab. Unfortunately the 1" module H6152 stopped working before measurements could be performed in a magnetic field.

4.1 Single Photo-Electron Spectra

Single photo-electron spectra are difficult to obtain with fine mesh PMTs since the amplification of the first stage is not very large. Useful spectra were obtained for the (high-gain) H6614 module where a single photo-electron peak could be observed while for the relatively low gain H6152 module only a shoulder could be observed. The spectra were produced by reducing the LED light output in such a manner the only about 1% of all the triggers produced a PMT signal above the pedestal. Figure 2 shows the obtained SPE spectra for the XP2020, R5924(H6614) and the R5505(H6152) respectively. From these

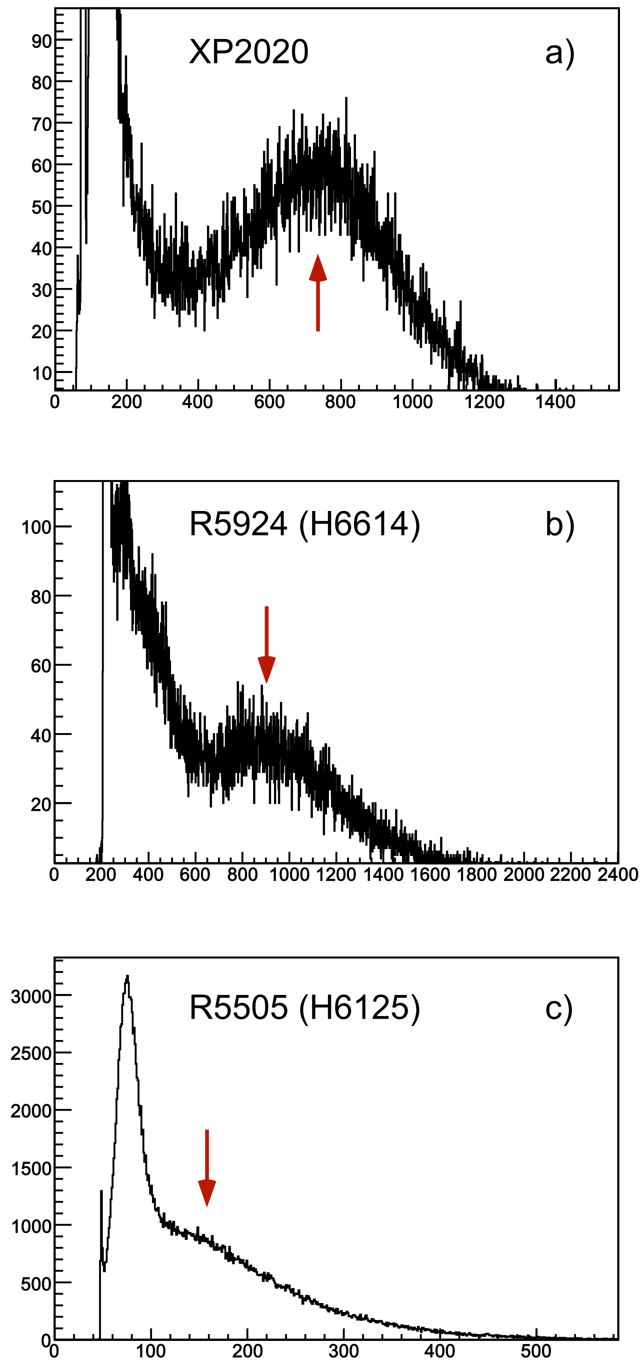

Figure 2: Single photo-electron spectra measured for the reference tube XP2020 (a) the 2" fine mesh tube R5924 (module H6614) and for the 1" fine mesh tube R5505 (module H6152). The arrow indicated the location of the single photo-electron peak. For module H6215 the 'peak' is only a shoulder

spectra the gain of the two PMT's was determined to be between $4{\cdot}10^7$ and $4.8{\cdot}10^7$ for the H6614 module and $5{\cdot}10^5$ for H6152.

4.2 Timing Measurements

Using the setup show in figure 1 and without a magnetic field the performance of the tubes were compared to the performance of well known PMTs: the H6152 was compared to the XP2262 (Photonis) and the H6614 was compared to the XP2020 (Photonis). In both cases the the width of the peak in the TDC spectrum was determined as a function of light output of the LED. Using the known gain of the PMT and the location of the SPE peak, an approximate value for the number of photo-electrons could be determined. For low light levels the shape of the TDC peak was very asymmetric and reflected the exponential decay of the LED intensity due to the discharge of the capacitor. With increasing light level the TDC peak narrowed and became symmetric. This behavior is very similar to what one expects from the light produced in a scintillator and where the timing resolution is given by

$$\sigma_{exp} = \frac{\sqrt{\sigma_{TTS}^2 + \tau_{sct}^2}}{N_{PE}}$$

where σ_{TTS} is the transit time spread of the PMT and τ_{SC} is the scintillation light decay constant. By plotting $\sigma_{exp}^2 \times N_{PE}$ as a function of N_{PE} one can test the validity of this assumption and compare the two photo multipliers.

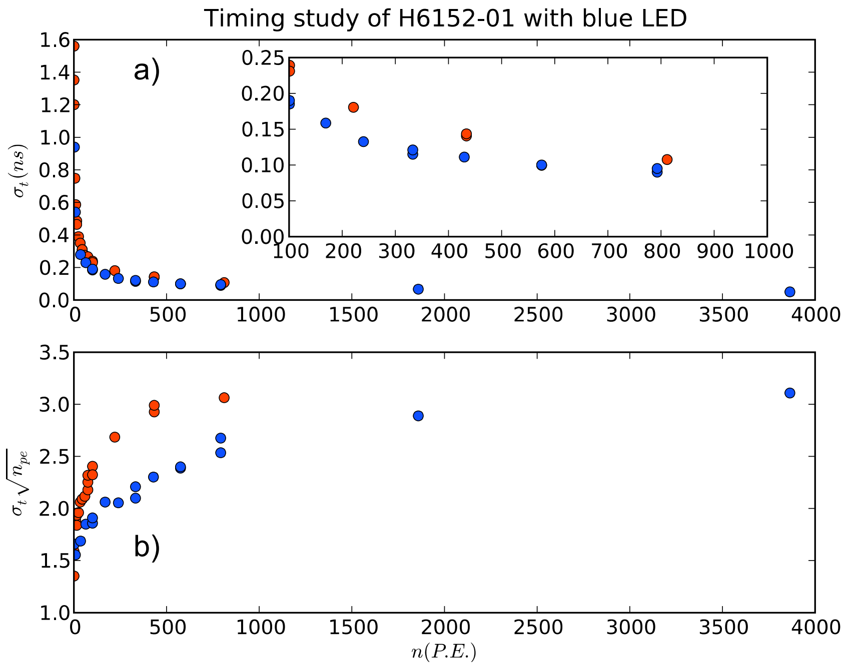

Figure 3: a) Timing resolution measured with a blue LED for the module H6152-01 (red symbols) and for the XP2262 (blue symbols) as a function of number of photo-electrons (N_{PE}). The inset shows a magnified region of this graph. b) The quantity $\sigma_{exp} \times \sqrt{N_{PE}}$ as a function of N_{PE}.

4.2.1 Timing Measurement results for module H6152

The reference tube for these measurement was the XP2262. The observed time resolution as a function of estimated photo-electrons is shown in figure 3 (a). In panel (b) in the same figure the quantity $\sigma_{exp}^2 \times N_{PE}$ has been plotted as a function of N_{PE}. Note that for $N_{PE} > 200$ this value is almost constant and $\approx$ 3 ns. It is larger than the corresponding value for the XP2262 by about 20%. This can be attributed to an uncertainty in the determination of N_{PE} for the fine mesh tube. Both values are quite close to the observed decay time of the signal on the scope. Overall the timing performance of the H6152 in this test is comparable to the one of the XP2262. And one can conclude that this tube would be suitable for timing applications.

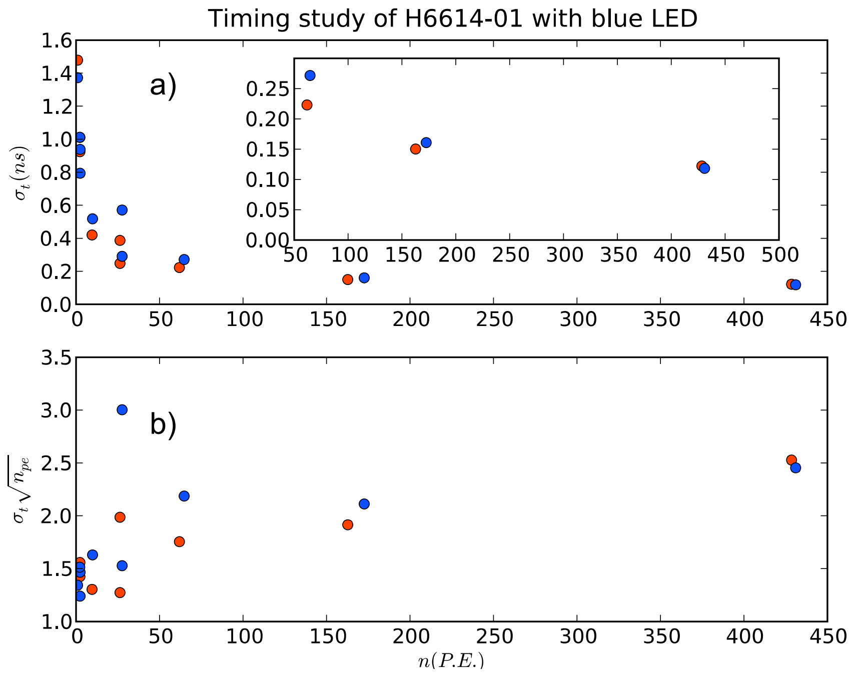

Figure 4: a) Timing resolution measured with a blue LED for the module H6614-01 (red symbols) and for the XP2020 (blue symbols) as a function of number of photo-electrons (N_{PE}). The inset shows a magnified region of this graph. b) The quantity $\sigma_{exp} \times \sqrt{N_{PE}}$ as a function of N_{PE}.

4.2.2 Timing Measurement results for module H6614

The module H6614 with the 2" fine mesh PMT tube has been compared to the XP2020 tube. The light output of the two fibers were approximately the same. This has been tested be exchanging the optical fibers and comparing the SPE spectra. The results of the timing measurements are shown in figure 4. The the same quantities are displayed as described for figure 3. For this set of measurements the two tubes are very close in their performance and the constant that is approached has a value of 2.2 ns for about $N_{PE} \approx 480$. This is again in the same range as has been observed for the 1" fine mesh tube module. As a consequence the H6614-01 is clearly a tube that can be used for high resolution timing applications.

Figure 5: The fine mesh PMT module H6614 in the gap of the BigBite magnet in Hall A. The blue arrow indicates the direction of the magnetic field and the yellow arrow indicates the direction of the PMT axis. The angle between the two directions is labeled θ in this report.

4.3 Measurements in Magnetic Fields

The module H6614 has been tested in magnetic fields up to 1.2 T using the Bigbite magnet of Hall A. A picture of the setup is show in figure 5.

The PMT module has been placed close to the center of the magnet where the field is homogeneous. This made it possible to have a well defined angle between the field direction and the axis of the PMT. We have measured the signal size as a function of field strength when the PMT axis was parallel to the magnetic field ($\theta = 0$).

If the axis of the PMT is parallel to the magnetic field the gain loss seems to be mainly due to a reduction in the multiplier while the collection efficiency is not affected. Fig 6 show the ADC spectrum without and with a magnetic field parallel to the axis of the PMT. One can see that the two peaks are

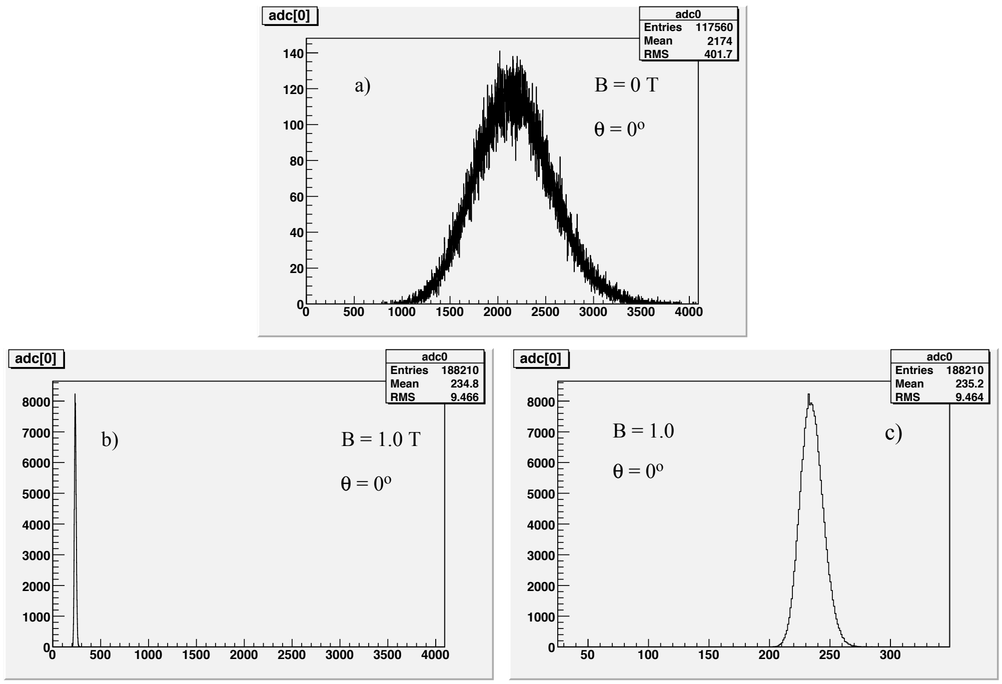

Figure 6: a) H6614 ADC spectrum for B=0. b) H6614 ADC spectrum for B = 1.0T with the magnetic field parallel to the axis of the PMT c) Same as (b) but for the first 10% of the spectrum ($\theta = 0°$). The light intensity used corresponded to about 27 photo-electrons at no magnetic field.

very similar and no change in structure can be observed. This is even more prominent in fig. 6(c) which shows just the first 10% of the ADC range. For field strengths of 0.487, 0.75, 1.0 and 1.2 T we determined the relative gain variation and the timing resolution as a function of the angle between the PMT axis and the magnetic field direction.

Figure 7 shows the comparison between the ADC spectrum taken at an angle of $\theta = 28°$ and the one taken at $\theta = 51°$ between the PMT axis and the magnetic field. The magnetic field strength was 0.487 T. The structure of the ADC spectrum has changed in a fundamental way. At an angle of 51° the spectrum is basically a single photo-electron spectrum (see fig. 7(c) where only the first 10% are shown). This shows that in this case the reduction of the PMT signal is due to a loss of collection efficiency.

From the ADC spectra we can conclude that the magnetic field causes gain variations by affecting the collection efficiency and by reducing the amplification in the dynodes. At large ($> 50°$) angles between the PMT axis and the

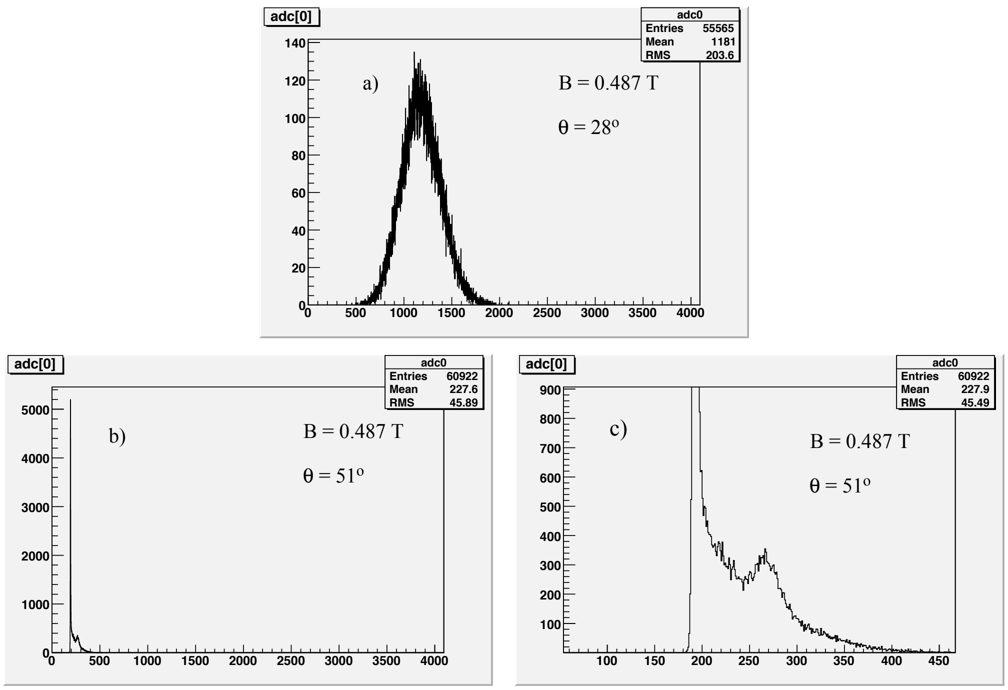

Figure 7: a) H6614 ADC spectrum for B=0.487 and $\theta = 28°$. b) H6614 ADC spectrum for the same magnetic field but with an angle of $\theta = 51°$ with the magnetic field and the PMT axis. c) Same as (b) but for the first 10% of the ADC spectrum only. The light intensity used correponded to about 28 photo-electrons at no magnetic field.

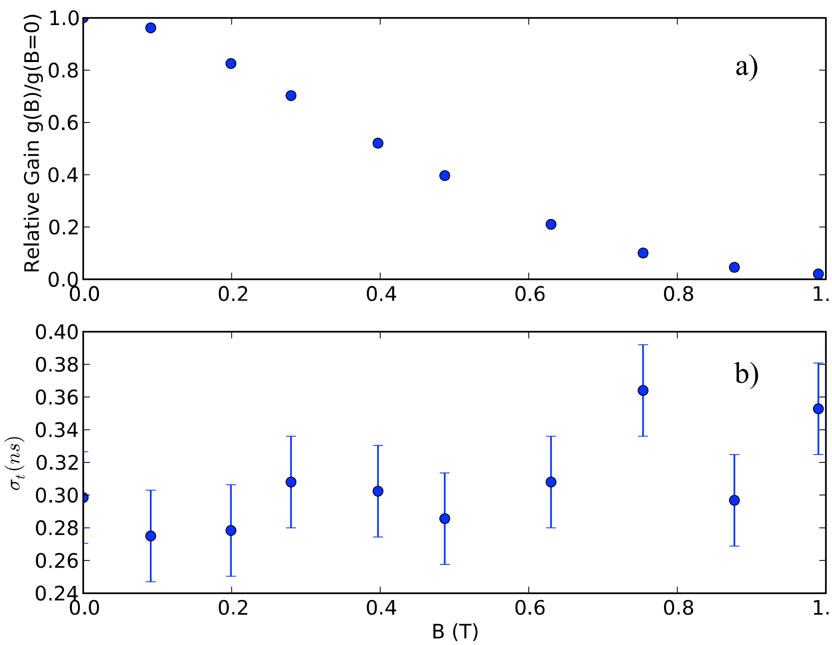

Figure 8: a) Gain variation as a function of magnetic field strength for $\theta = 0°$. b) Timing resolution as function of magnetic field for $\theta = 0°$. The light intensity at zero magnetic field corresponded to about 28 photo-electrons.

magnetic field, the observed signal loss is due to a reduced collection efficiency. At smaller angles the reduced signal is due to a loss of amplification in the multiplier. As a consequence we expect a clear reduction of timing resolution for large angles and only slight variation for angles smaller than 45°.

This has been confirmed by the measurements the timing resolution as a function of the strength of the magnetic field and as a function of the angle between the field and the PMT axis. Fig. 8 shows the relative signal variation(a) and timing resolution(b) for $\theta = 0°$ as a function of the magnetic field strength. While the gain has been reduced by about a factor 50 the timing resolution has a only been degraded by about 20%. Fig. 9 shows the signal amplitude variation(a) and the timing resolution(b) as a function of the angle θ for a range of magnetic fields. The sharp drop off of the signal size combined with the sharp degradation of the timing resolution for angles larger than 50° is due to the loss of collection efficiency.

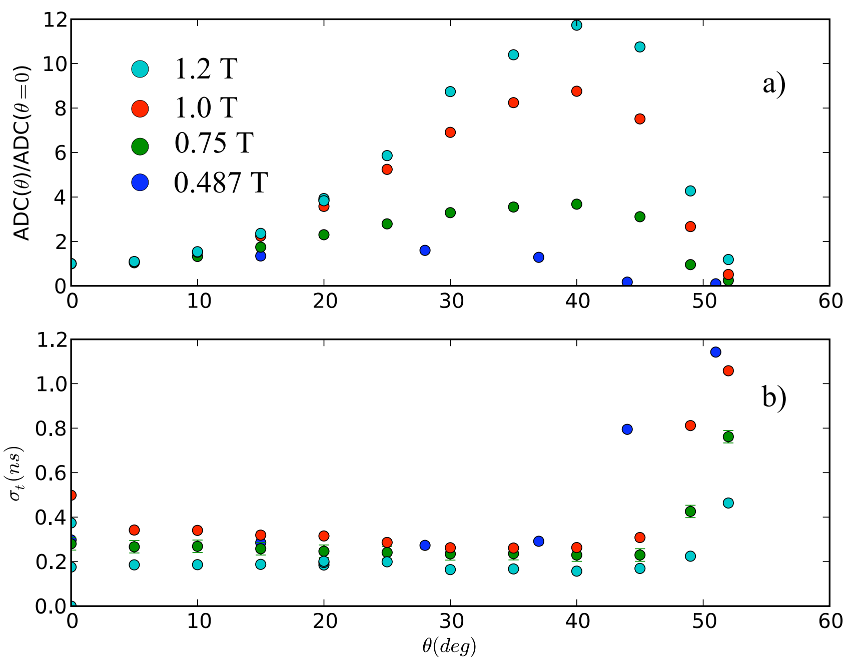

Figure 9: a) PMT signal as a function of θ relative to $\theta = 0°$. b) Timing resolution as a function of θ. The light intensity at zero magnetic field corresponded to 27 - 34 photo-electrons for fields below 1.2T and 160 photo-electrons for the 1.2T measurement. The improved resolution with increasing magnetic field is due to the fact that the light intensity has been increased slightly with increasing magnetic field.

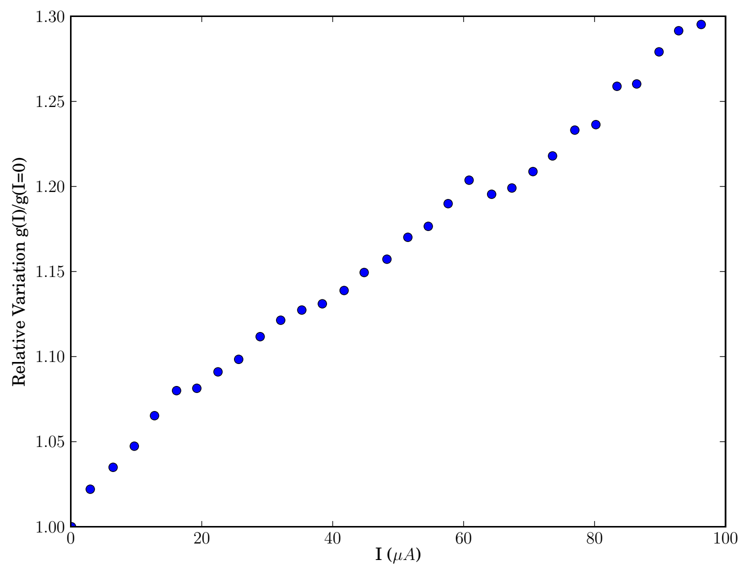

Figure 10: Relative gain variation as a function of anode current. The maximum corresponds to a rate of 300kHz with a typical pulse size of about 180 photo-electrons.

4.4 Gain Variation Measurements

The results of a measurement of the gain variation as a function of back ground rate is shown in figure 10. The supply voltage for this measurement has been 1.7kV.

5 Summary

We have tested the Hamamatsu fine mesh PMT models H6152-01 and H6614-01 regarding their timing performance. The module H6614-01 has also been tested in magnetic fields of up to 1.2 T for angles ranging from $0° - 52°$ between the field direction and the axis of the PMT. Both tubes have timing performances that are comparable to the XP2262 and the XP2020 tubes which would them make suitable for timing measurements in GlueX. The gain of the H6614 decreases considerably for high magnetic fields while it's timing performance remains relatively constant as long as the angle between the magnetic field and the axis of the PMT (or the normal to the PMT face) remain at an angle smaller than 45°. Above this angle, timing resolution and gain degrade rapidly which is attributes to a loss in photo-electron collection efficiency. For the H6614 an optimal range of angles between the axis of the PMT and the magnetic field would be between 30° and 40°. For the module H6152 measurements in high magnetic fields are still needed.

References

[1] B K Lubsandorzhiev *et al.*, JINST **1** (2006) T06001.

[2] J.S. Kapustinsky *et al.*, Nucl. Instr. Meth. **A241** (1985) 612.