Photomultiplier Tests for the CLAS TOF

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1 Introduction

Apparatus has been set up for the purpose of testing the timing performance of photomultiplier tubes (PMT) [1], which might be used in the CLAS time-of-flight (TOF) scintillator counters [2]. The TOF scintillators are 5 cm thick so minimum-ionizing particles deposit a minimum of 10 MeV, producing typical pulses in each PMT of roughly 200 photoelectrons. Even under these circumstances, the time resolution is often limited by photostatistics [3]. A cost effective solution to cover a large area is achieved by using 2", 12-stage PMTs, which is the option we are presently investigating. This setup is designed to compare tubes from various manufacturers, as well as aid in the selection of a specific voltage divider network. At this time we report on the comparison of four 2" PMTs from potential commercial vendors.

2 Laser Source

The source of photons is provided by a LN120C nitrogen laser, [1] delivering 250 kW of peak power in 300 ps pulses, up to a rate of 20 Hz. The average power output is .75 mW at 10 Hz. The nominal wavelength is 337.1 nm. The RF radiation produced by the spark plug in the laser was shielded by enclosing the laser in an aluminum box designed for that very purpose [4]. The spot size at the location of the first beam splitter (Figure 1) is approximately 3×5 mm^2 The beam is first attenuated by a factor of 50 by a neutral density filter to reduce the number of photons to a level which is useful for our application. The beam is then transported through a filter wheel (FW) with five neutral density filters which are used to select the average light intensity delivered to the PMT. The pulse height in one of the PMTs was measured at

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[1]Laser Photonics, 12351 Research Parkway, Orlando, Fl 32826.

each FW setting (see Figure 5). The five filters allow the light intensity to be selected reproducibly by a factor of eight. The intensity profile is Gaussian with typical widths (σ) of less than 10%, although the nominal stability of the laser is 5%. The calibration (see Figure 6) of the light intensity in terms of number of photoelectrons for a reference PMT (see below), was estimated on a Tektronix 2467B oscilloscope by comparison of the single photoelectron noise pulses with the output for several filter settings. The uncertainty in this estimate is roughly 30%. The relative intensity of the various filters was determined by the QVT as mentioned above and known quite well.

3 Setup

An optical fiber which is illuminated by the laser transports the light pulses to a light-tight ("black") box containing two PMT assemblies. The laser light is used to excite the response in a small piece of Bicron 408 scintillator, which is then sent to each PMT via two other optical fibers (see Figure 2). By using a filter that absorbs all light below 389 nm we determined that very little of the direct light ($\leq$1%) from the laser reaches the PMTs. The fibers which illuminate the PMTs are inserted into an oversized hole in an acrylic cylinder. This cylinder is optically coupled to a second acrylic cylinder which mates with the PMT. The end of the fiber is 8.2 cm from the PMT window. In this way the entire photocathode is illuminated to approximate the geometry of the CLAS TOF counters. A fast signal (rise time $\leq$ 1ns) from a photodiode [2] is used as a reference time for the laser pulse. The PMT signals are discriminated with a Phillips 715 constant fraction discriminator (CFD). The threshold was set at -50 mV and a shaping delay of 2 ns.

In order to achieve the required time resolution in the QVT, the overlap of two logic pulses was integrated by operating the QVT in the "Q" or charge mode of operation. Refer to the logic diagram in Figure 3. The overlap of logic pulses is a linear function of time difference between them, as shown in Figure 4, as long as measurements fall between channels 400 and 900. The data were usually contained in the third quarter of the QVT memory, which corresponds to channels 500–750. The calibration in this region corresponds to 16 ps/channel.

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[2] P/N Diode, Motorola MRD 500.

4 Reference PMT

The first measurements were used to establish the validity of our procedure. Two Amperex XP2262 PMTs were installed in the black box, one of which would remain as a reference for future measurements. Data were taken at each filter wheel setting measuring the time difference between each PMT and the laser pulse determined by the P/N diode. We also measured the time jitter between the two PMTs. Systematic contributions to the resolution were estimated by increasing the number of photons to a point where the resolution of the PMT was negligible. This was accomplished by removing the 2% neutral density filter. The contribution due to the electronics alone was determined to be 14ps by timing one PMT relative to the other. The resolution of the diode (40 ps) was obtained by measuring the jitter of one PMT compared to the diode signal and subtracting the small contribution due to the electronics.

Raw distributions of the time measured by one PMT relative to the diode are shown in Figure 7. The time resolution is determined statistically and varies inversely with the square of the number of photons, as shown in Figure 8, where this behavior is indicated by a straight line on a log-log plot. The time of one PMT relative to the other is consistent with the assumptions that the individual measurements are independent and their widths may be added in quadrature. The reproducibility and consistency of the measurements were tested by comparing two sets of data taken three weeks apart, during which time the assembly was taken apart and put back together. These are shown in Figure 9. A typical run had a statistical error on the width of 4%.

5 Results

Four comparable PMT types from EMI (9954B05), [3] Amperex (XP2262), Burle (8575) and Hamamatsu (R329) were tested for their time performance. In each case two samples were obtained from the company and were tested in turn. In general, we used the high voltage divider network which was recommended by the company for the tube they provided. In a few cases more than one base was tested. However the comparison between various

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[3]EMI 9954B PMTs selected for high values of single electron resolution (SER). The peak-to-valley ratios of the single electron spectrum for the tubes tested were 2.5 and 2.1.

designs of the high voltage divider will be discussed in a later document. The circuits of the bases which are presented here are shown in Figures 10 – 12. The reference PMT described above remained installed throughout the procedure and its response was remeasured for FW3 at the time the data were taken for each tube.

A scan over high voltage was performed to determine the best operating point for each PMT (see Figure 13). The PMT was then set at the voltage that yielded the smallest resolution for FW4 ($\sim$277 photoelectrons). The gains of the PMTs were in general different due to the procedure for selecting the voltage setting. Once the voltage was determined, the PMT inputs to the CFD were attenuated so that the discriminator (threshold = –50 mV) was operated over the region of $\sim$1.2 – 20 times threshold for the five filter wheel settings. The required dynamic range response of the electronics was thus similar for all measurements.

The time resolution was then measured at the five filter settings, the number of photoelectrons spanning the range expected for the CLAS TOF counters (41–337 photoelectrons/PMT). The measurements are summarized in Figures 14– 16. For ease of comparison, the data from each tube was fit to the form $a + b/\sqrt{N_{pe}}$, where N_{pe} is the number of photoelectrons. The fits are shown in Figure 17. The estimated resolution for 200 photoelectrons from the fit is tabulated in Table 1. Our goals require that the contribution due to PMTs and electronics be less than 140 ps for 200 photoelectrons uniformly distributed on the face of the PMT. All PMTs which we tested can be considered for use in the CLAS TOF system based on these tests. However, the Burle 8575 tubes tested 30-40% worse than the other three, a possible reason being the voltage divider network used might not be optimum.

Table 1: Summary of PMT characteristics. The time resolution is quoted for 200 photoelectrons for the reference PMT. The actual number of photoelectrons for each PMT would vary depending on the value of its quantum efficiency.

PMT	Measured rise time (average) 10-90% (ps)	Resolution σ (ps)
Amperex XP2262	3.0	113
EMI 9954B05	3.3	101
Burle 8575	3.0.	144
Hamamatsu R329	4.0	103

References

[1] The initial phase of testing is described by S. Majewski in "Test Timing Setup for TOF PM's," CEBAF Internal Note, June 12, 1990.

[2] "Conceptual Design Report – Basic Experimental Equipment," CEBAF April 13, 1990.

[3] R.T. Giles *et.al.*, NIM **A252**, 41 (1986).

[4] R.A. Miskimen and K. Wang, "Prospects for Drift Chamber Calibration Using a Nitrogen Laser," CLAS-NOTE-91-002.

[5] G. Dumont and P. Duteil, "Specifications for a Photomultiplier Base Type 4244," CERN EP-ELECTRONICS Test and Instrumentation Group.

[6] ORTEC base designed for a Burle 8850 PMT.

[7] "Photomultiplier Tube Assemblies for High Energy Physics," Hamamatsu Technical Data T-115, p. 11.

List of Figures

Figure 1: The laser beam transport system consists of two beam splitters and a filter wheel. The laser itself is enclosed in an aluminum box to shield external instruments from RF radiation.
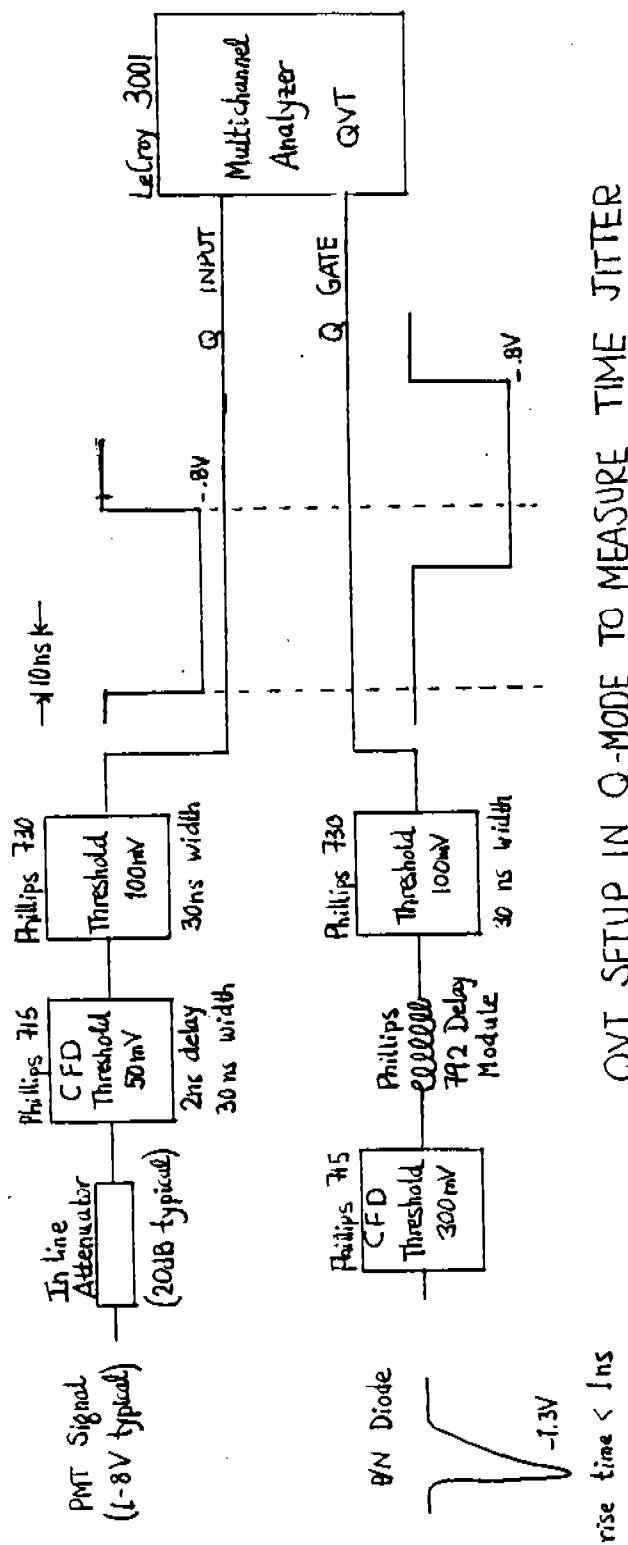
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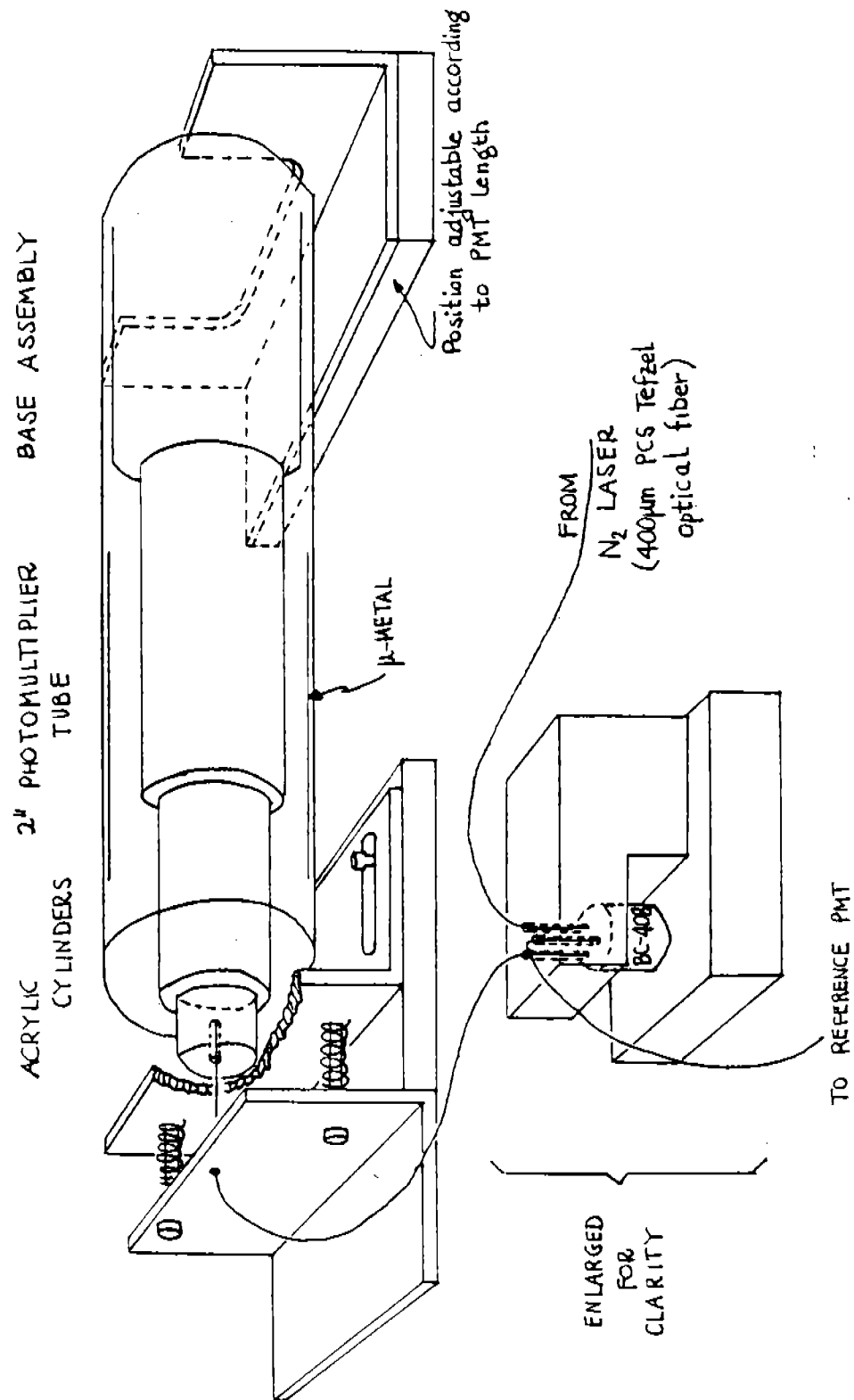
Figure 2: Setup showing the optical fiber connections to the PMT. The PMT assembly shown as well as the one referred to as the reference are placed in a light-tight box.

Figure 3: Logic diagram for timing circuit.

QVT Time Calibration

Slope=62.41ch/ns

Mean (Channel Number)

Delay Cable (ns)
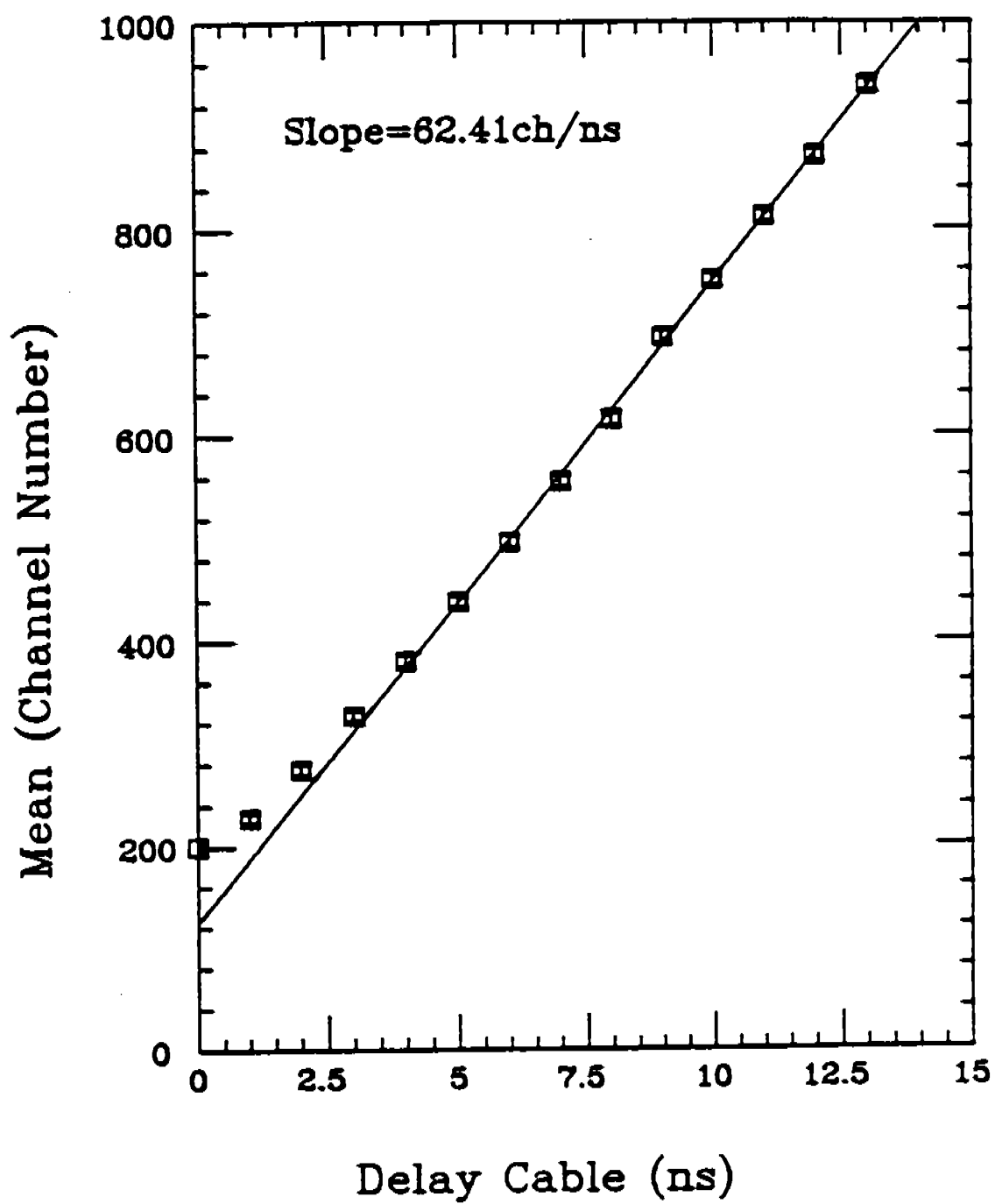
Figure 4: Time calibration of QVT.
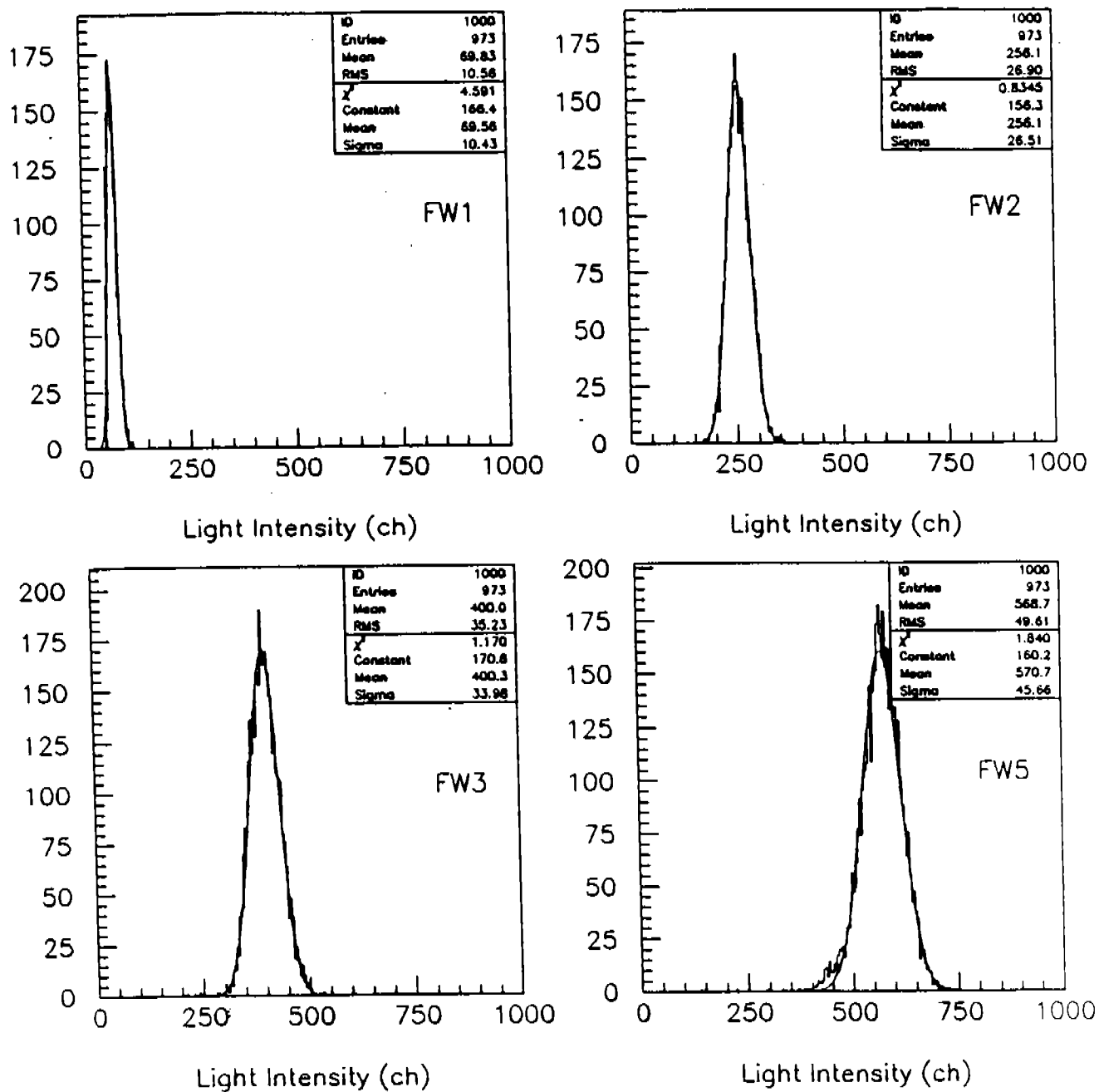
Figure 5: Light intensity for various FW settings.

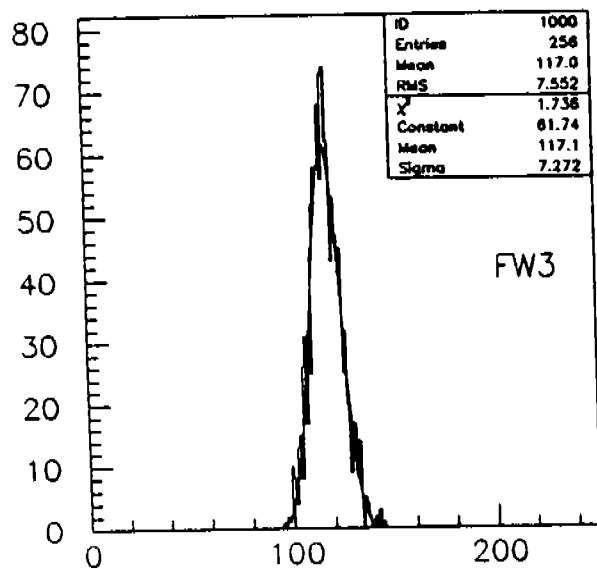# Laser Calibration
Full Illumination
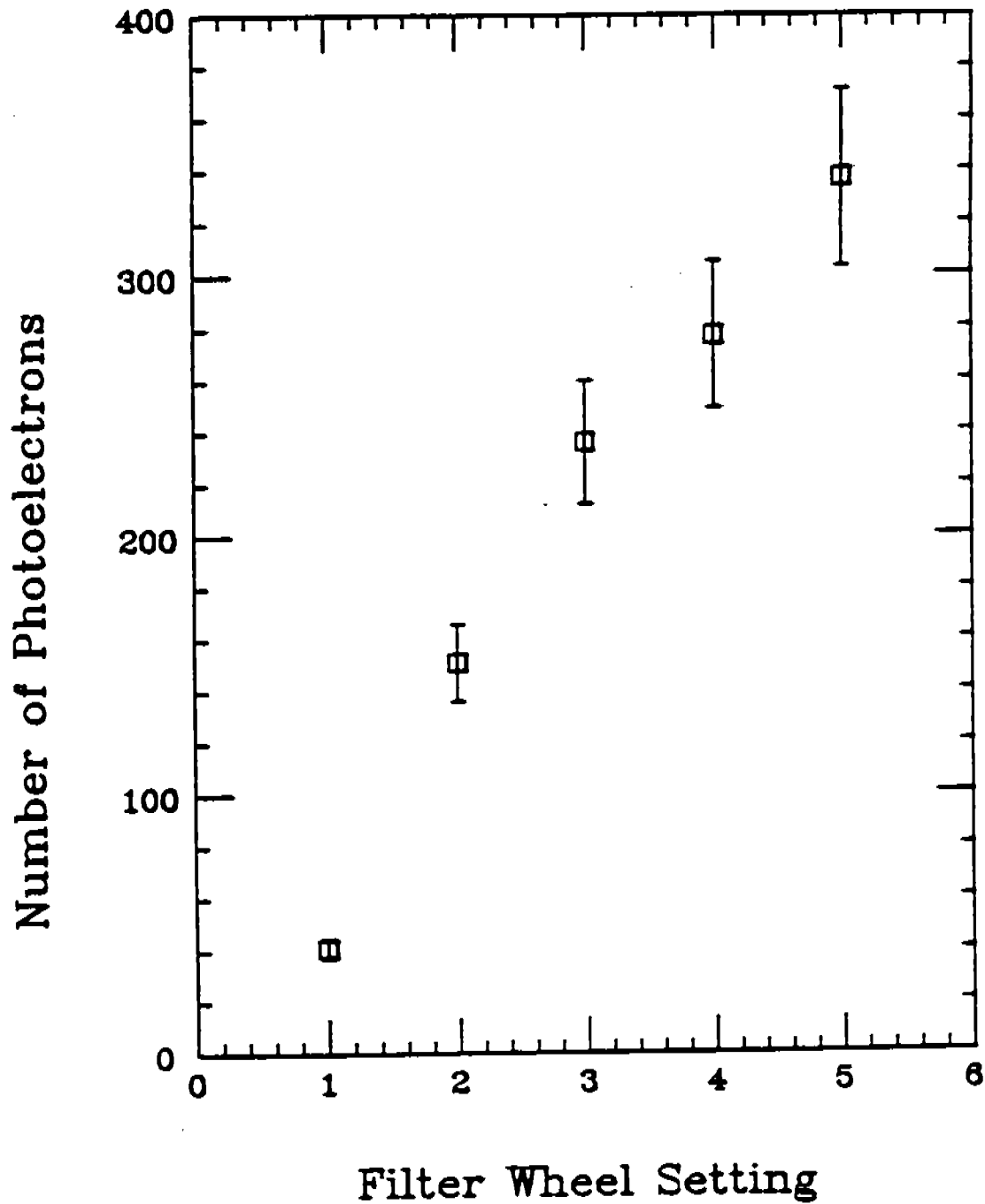
Figure 6: The light intensity for various FW settings is shown in terms of number of photoelectrons for a reference PMT. The absolute normalization is uncertain by 30%. The errors shown give the systematic reproducibility, including the couplings of optical fibers, of light collected by the PMT for a given filter setting.
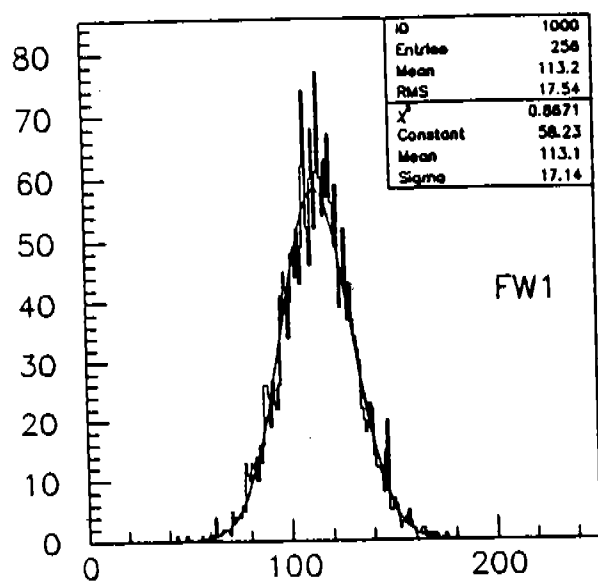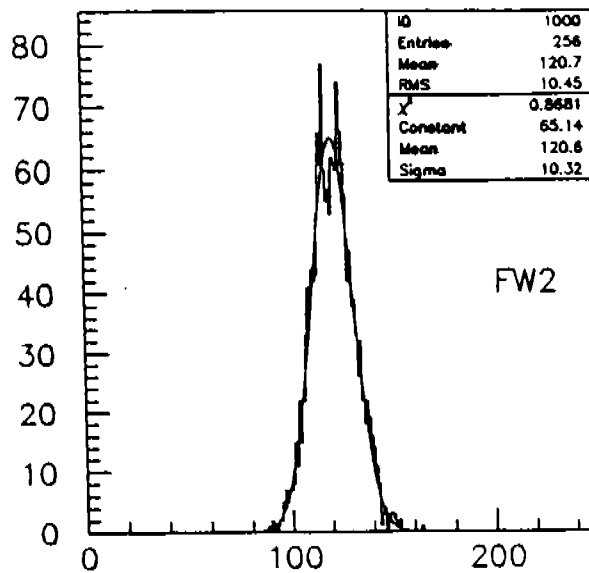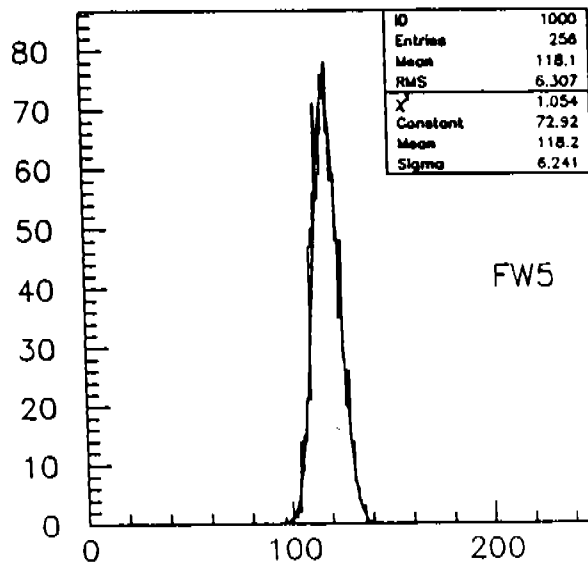
Figure 7: The time distributions of the reference PMT relative to the laser diode are plotted for several filter settings. The light intensity varies by a factor of eight between the first and fifth filter.

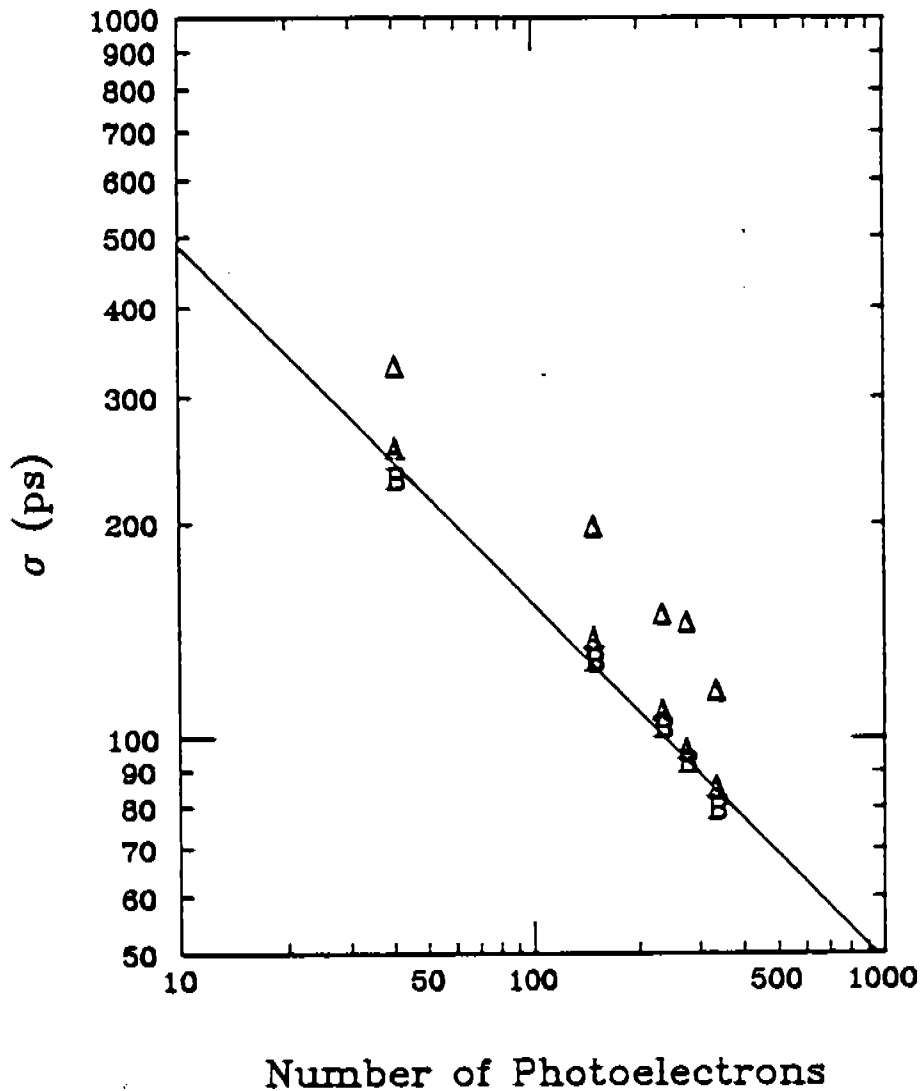**PMT Tests (Amperex XP2262)**
Full Illumination

Figure 8: Resolution of Amperex XP2262 vs number of photoelectrons. The measurements of two PMTs (A and B) are shown relative to the laser diode. The jitter of one PMT relative to the other (Δ) is also plotted. The line shows the expected statistical behavior given by the the inverse square root of the number of photoelectrons.

PMT Tests (Amperex XP2262)
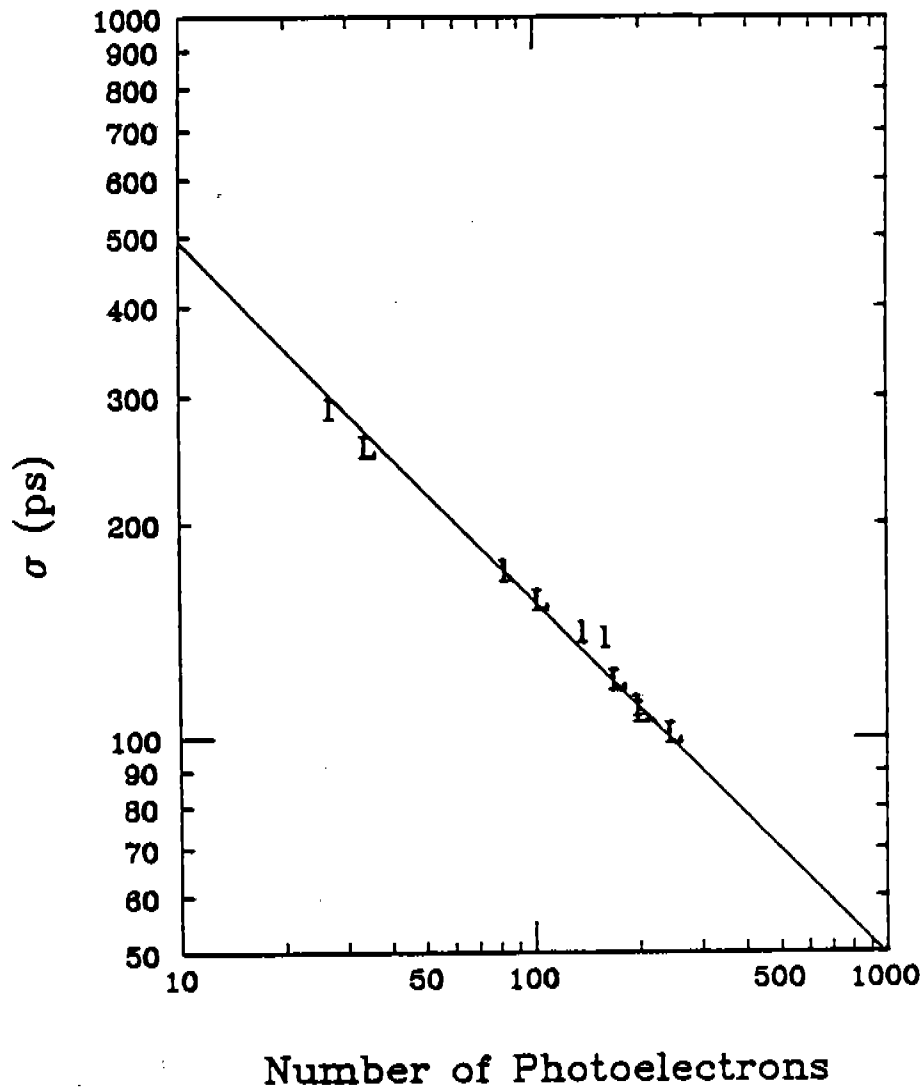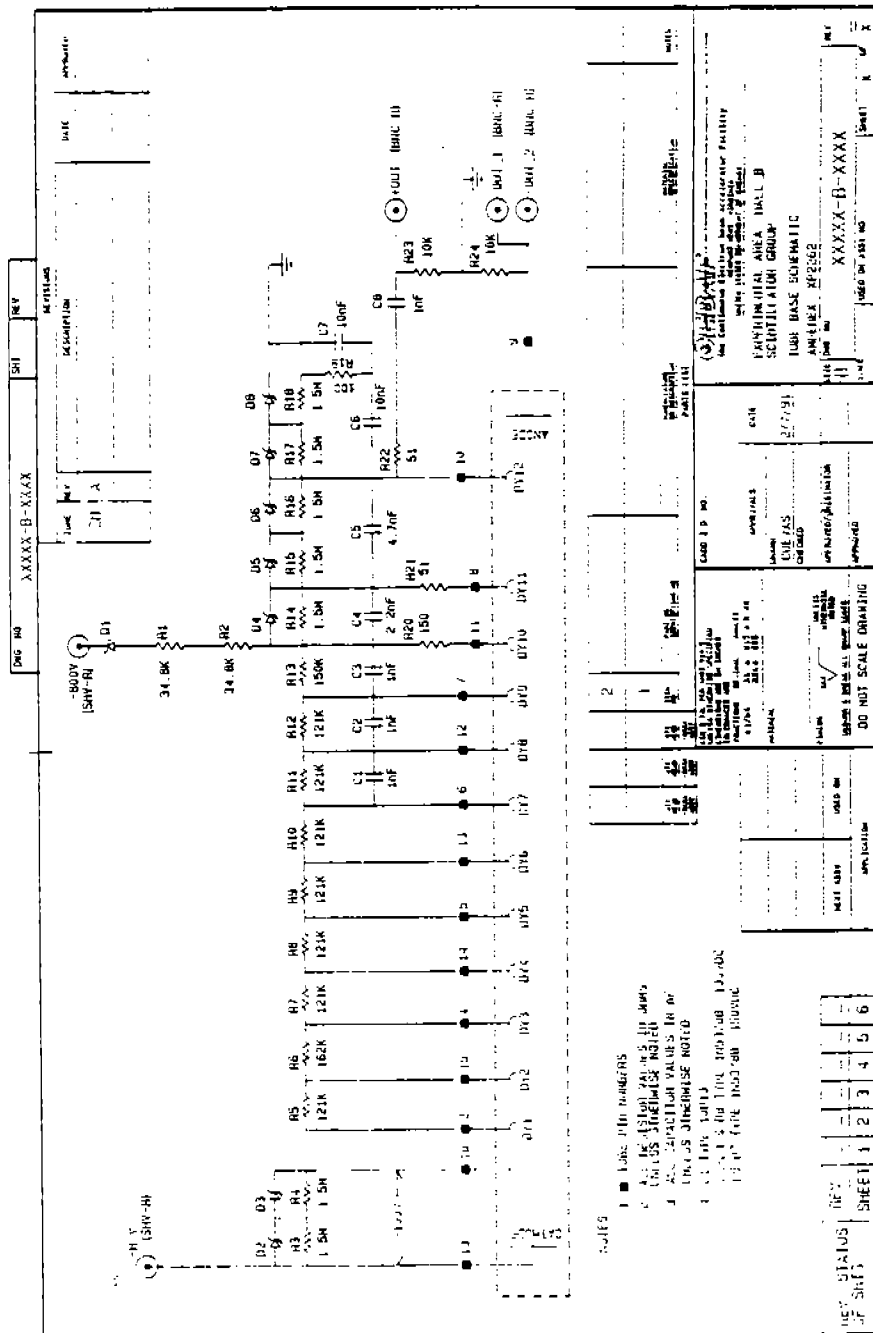## Full Illumination

Figure 9: Two sets of data taken three weeks apart (labeled by upper case L and lower case l) are plotted to show the reproducibility of the measurements.
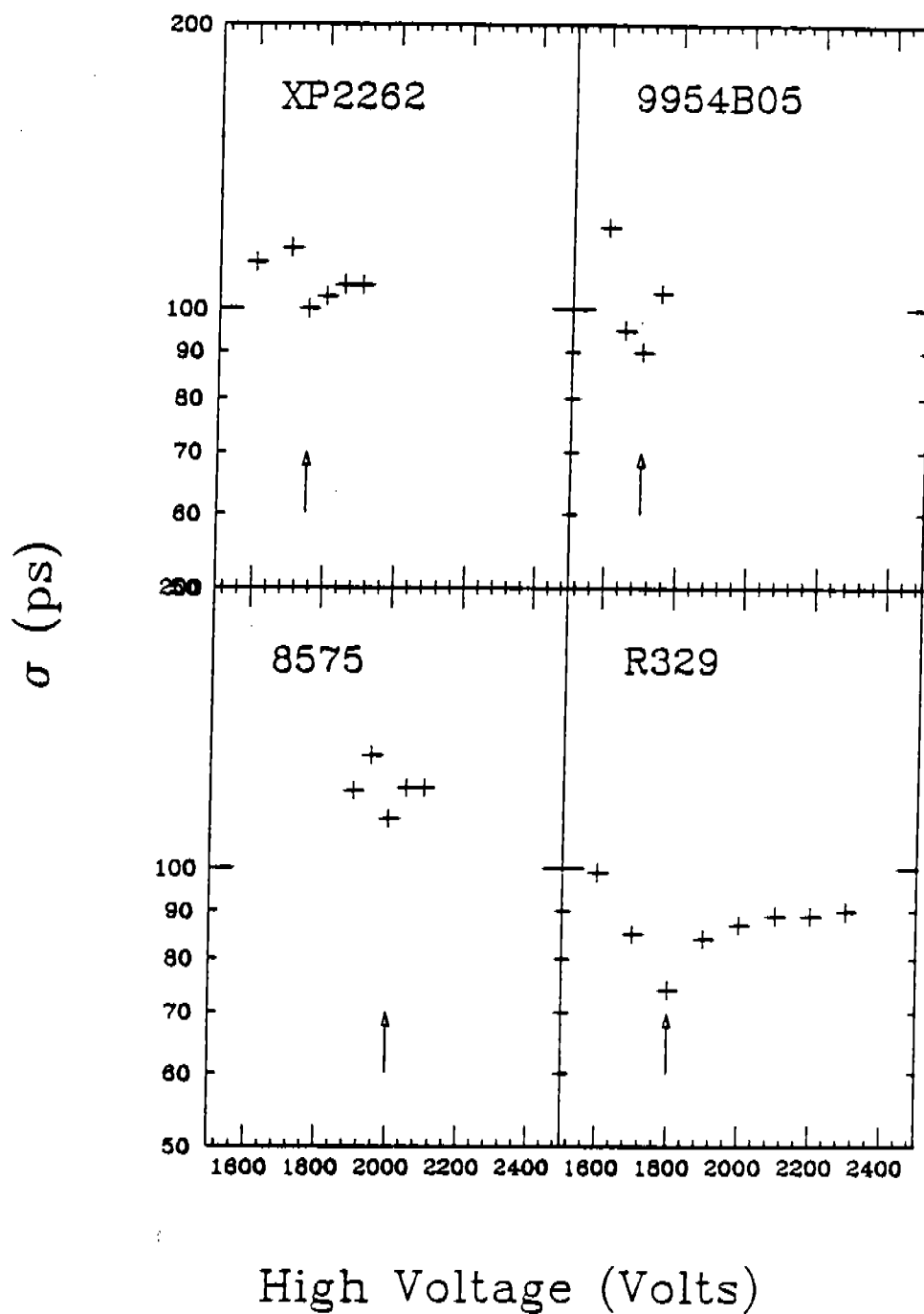
Figure 10: High voltage divider network used for the Amperex XP2262 and EMI 9954B PMTs. This is a CERN design [5].

Figure 11: High voltage divider network for Burle 8575 [6].

Figure 12: High voltage divider network for Hamamatsu R329. The base was provided by the company [7]. The dynode output was used for the tests presented here.

Figure 13: Time resolution measured as a function of high voltage for the four PMTs. The operating point was selected to obtain the smallest resolution for FW4.
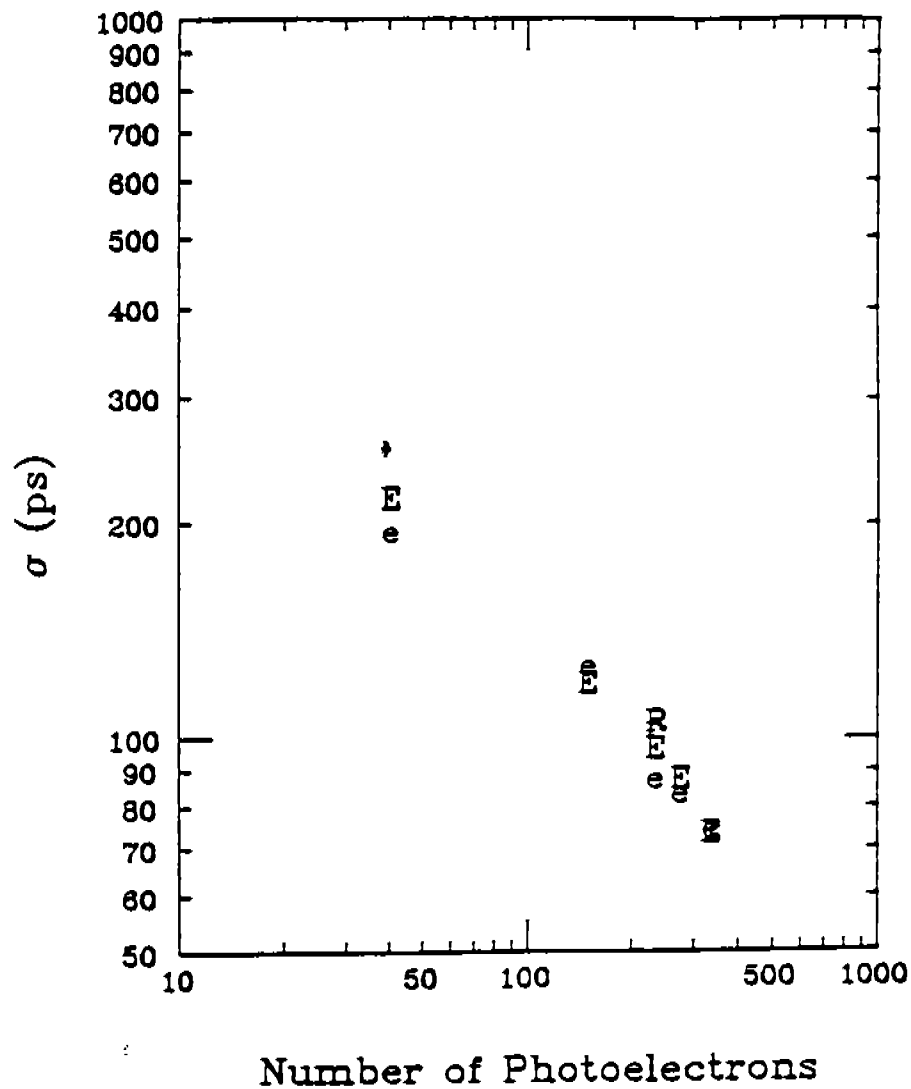
PMT Tests (EMI 9954A)
Full Illumination

Figure 14: Resolution of EMI 9954B05 vs number of photoelectrons. The measurements of two samples (labeled by upper and lower case) are shown relative to the diode time. The reference PMT measurements are indicated by the letter "R."
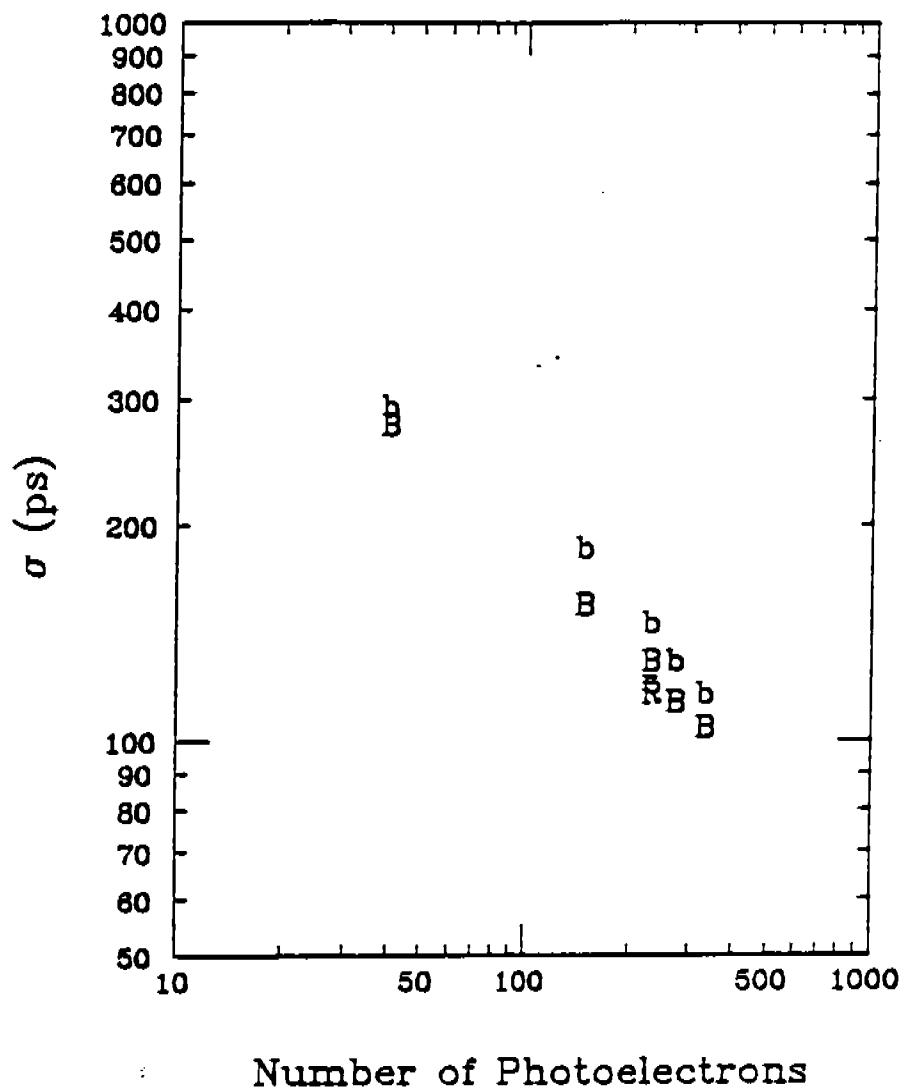
Figure 15: Resolution of Burle 8575 vs number of photoelectrons. The measurements of two samples (labeled by upper and lower case) are shown relative to the diode time. The reference PMT measurements are indicated by the letter "R."
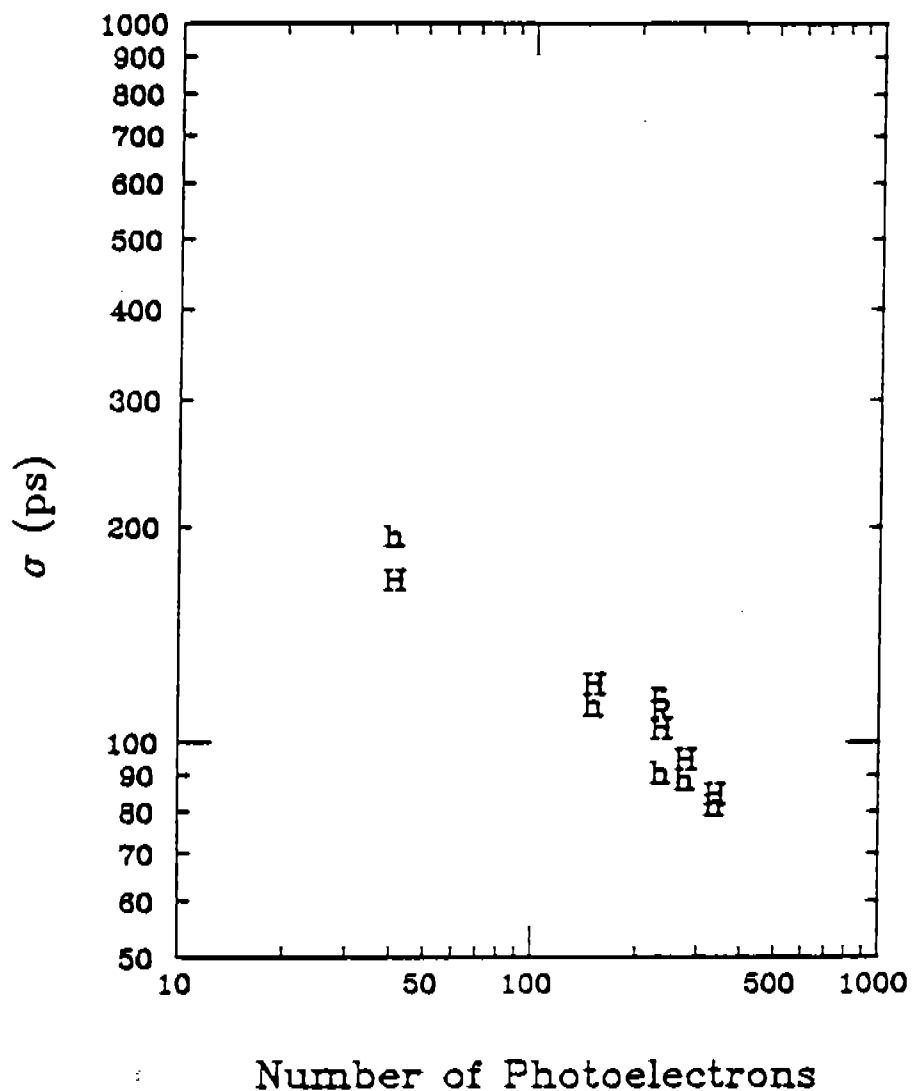
PMT Tests (Hamamatsu R329)
Full Illumination

Figure 16: Resolution of Hamamatsu R329 vs number of photoelectrons. The measurements of two samples (labeled by upper and lower case) are shown relative to the diode time. The reference PMT measurements are indicated by the letter "R."
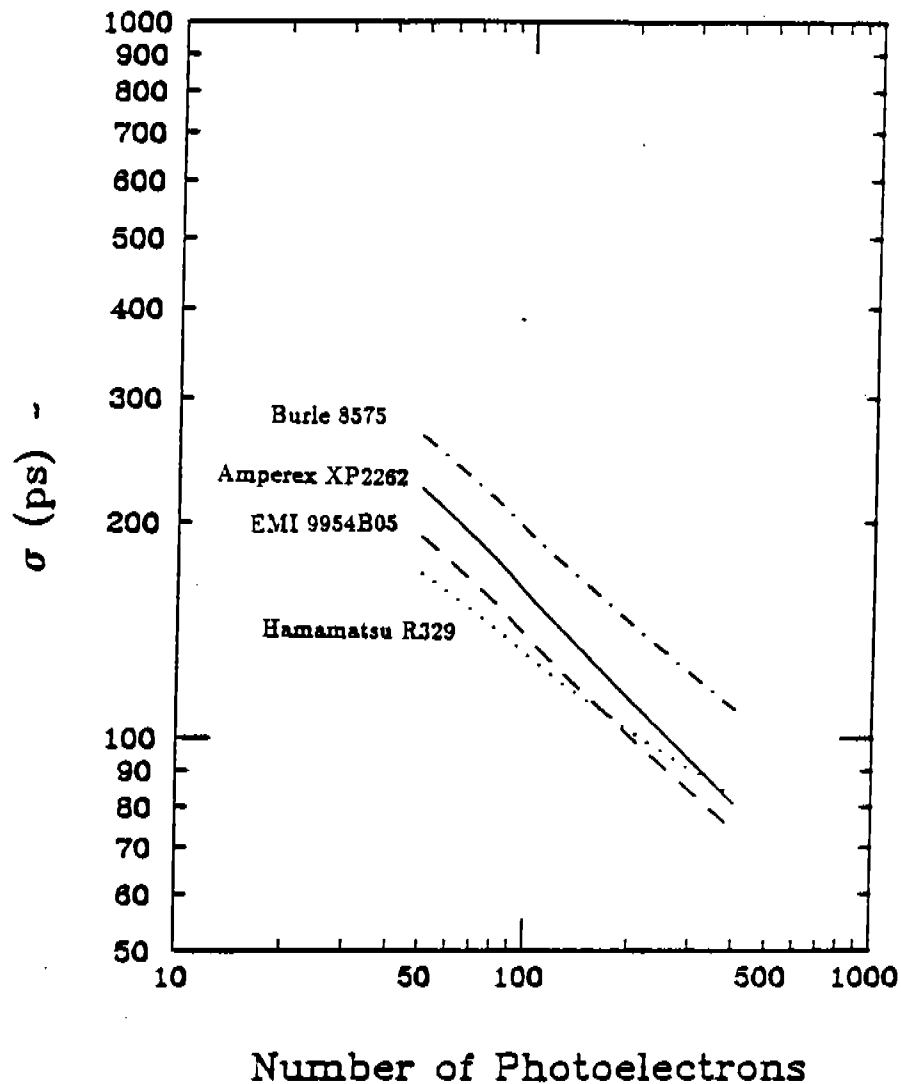
PMT Tests (Comparison)
Full Illumination

Figure 17: Resolution of the four PMTs tested. The lines are empirical fits to the data and are useful for the purpose of comparing the various PMTs.