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Design and Testing of Light Guides for the CLAS Detector[1]

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fabricated by Bicron, was expected to have the best light collection if tested under the same conditions as the other guides. All precautions were taken to keep the testing conditions the same; the results indicate the limitations in the measurements. We note finally, that the best light guide design depends critically on the surface quality after bending. Thick pieces are strained during the bending and the two surfaces of the guide cannot remain parallel. However, the greater number of sheets which are required for laminated guides add complexity to the fabrication. The goal of these studies will be to optimize the design of these light guides.

References

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

[2] Thomas Massam, *Nucl. Instr. and Meth.* **141**, 251 (1977).

[3] S. Banerjee *et.al., Nucl. Instr. and Meth.* **A269**, 121 (1988).

[4] S. Margulies and J. Ozelis, "A Fast VUV Pulser for Testing Ring-Imaging Cerenkov Counters," University of Illinois at Chicago.

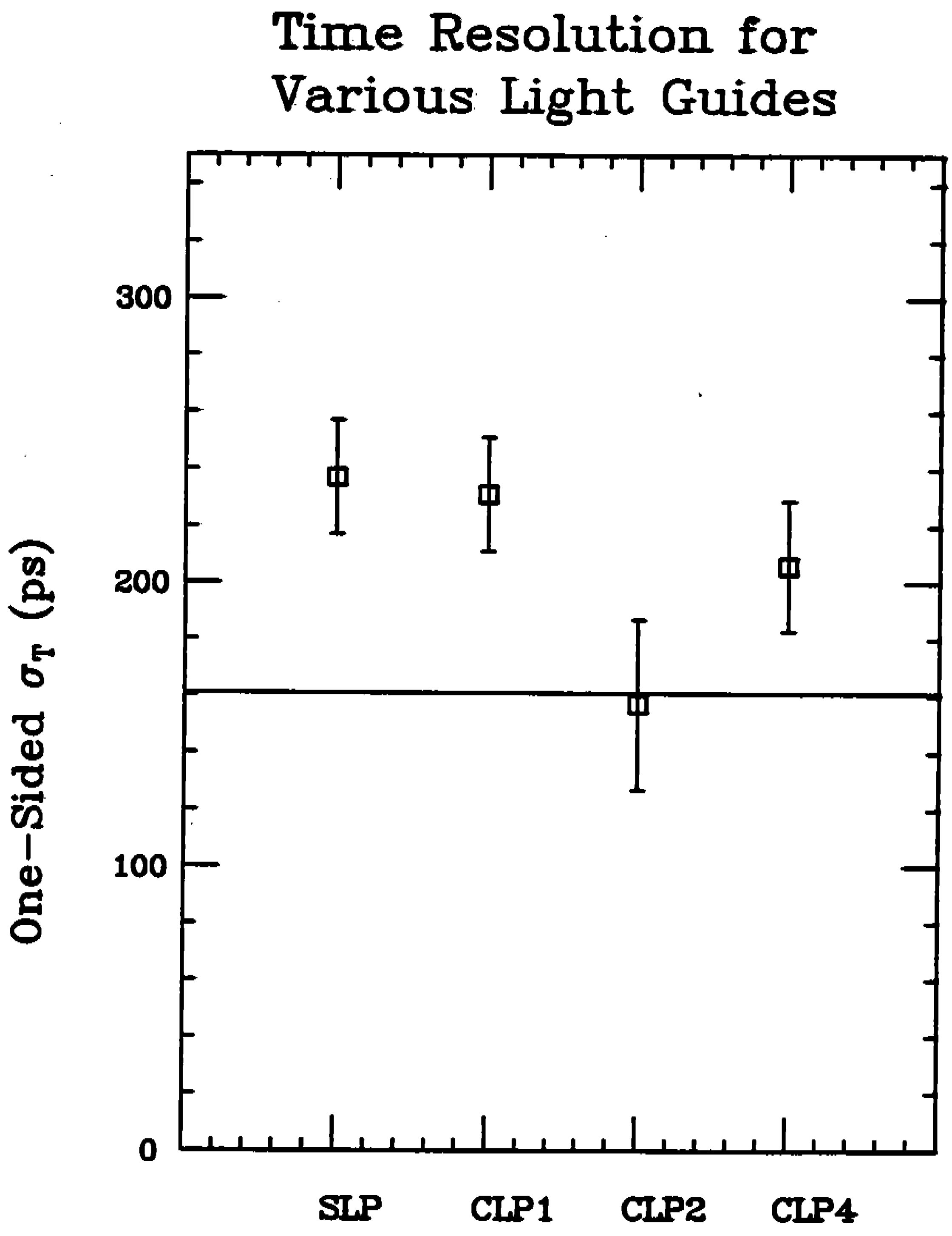

Figure 10: Comparison of the measured performance of the light guides which were tested relative to the goal of a $80 \times 20 \times 5 cm^3$ TOF counter for the CLAS detector. The error bars reflect a 20% systematic uncertainty in the light intensity deposited in the scintillator.

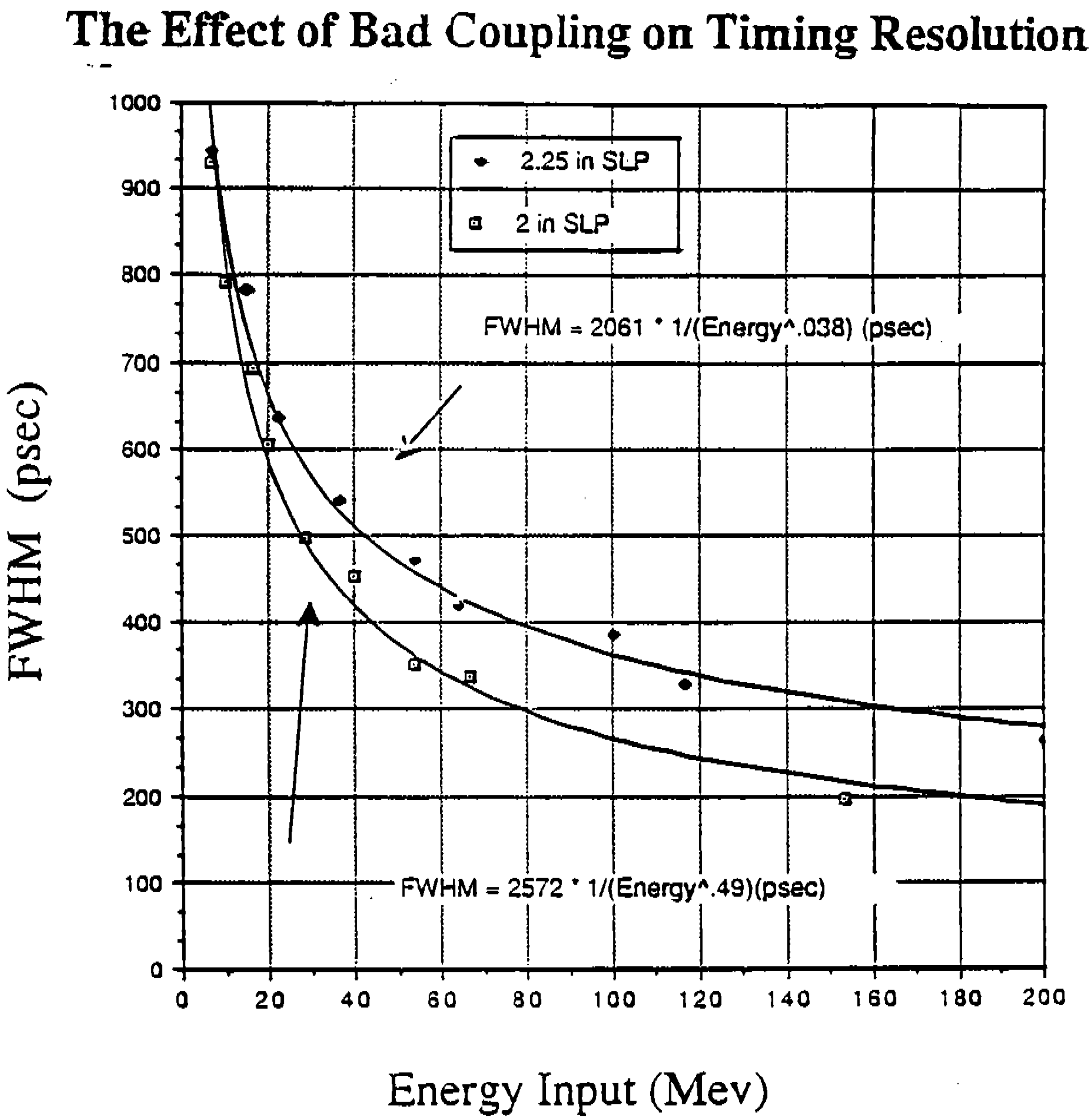

Figure 9: Comparison of two straight light guides of comparable quality. The relatively poor resolution obtained with the 2.25" piece is due to the loss of light due to poor optical coupling.

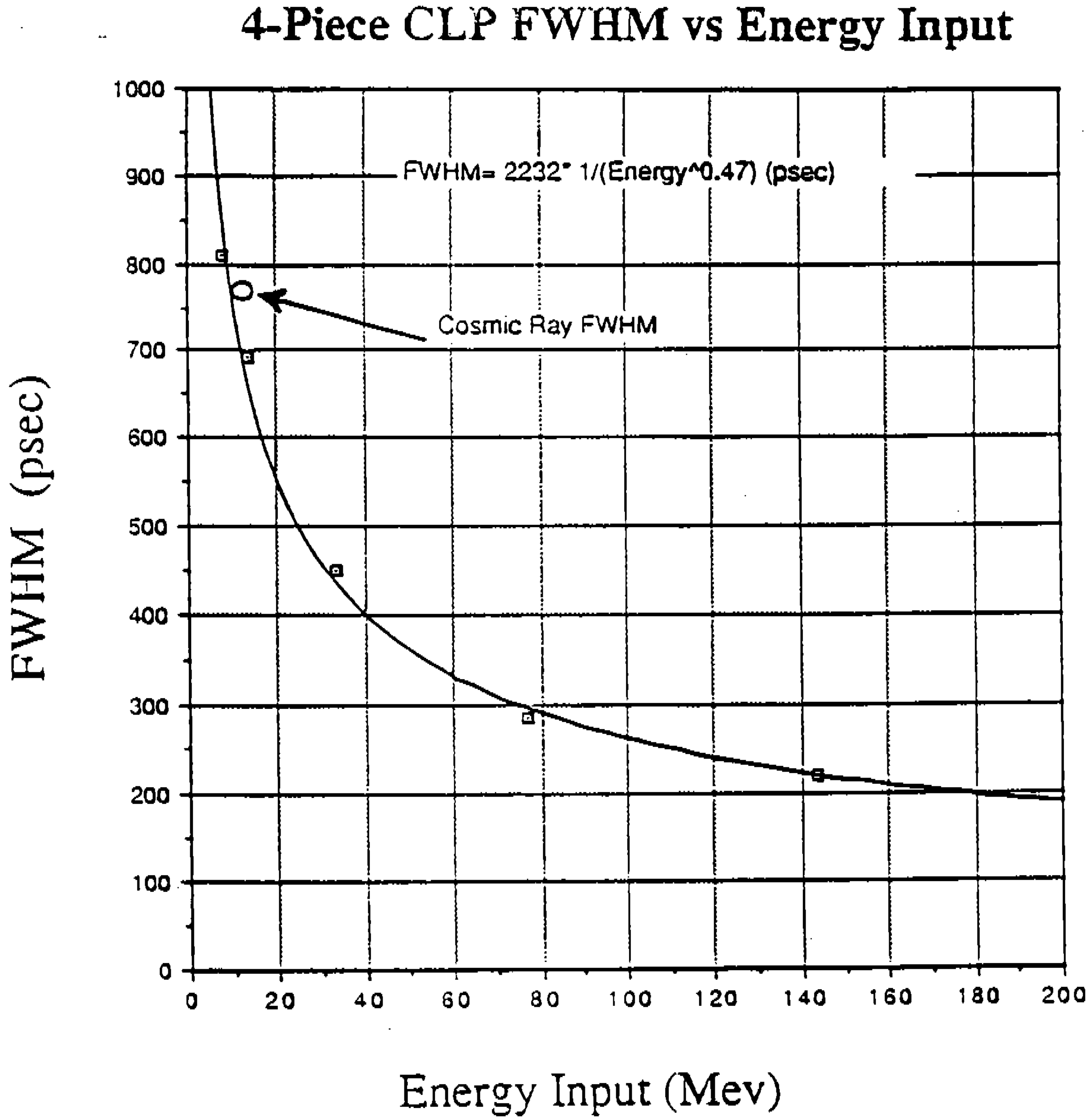

Figure 8: FWHM vs energy for 4-piece curved light guide.

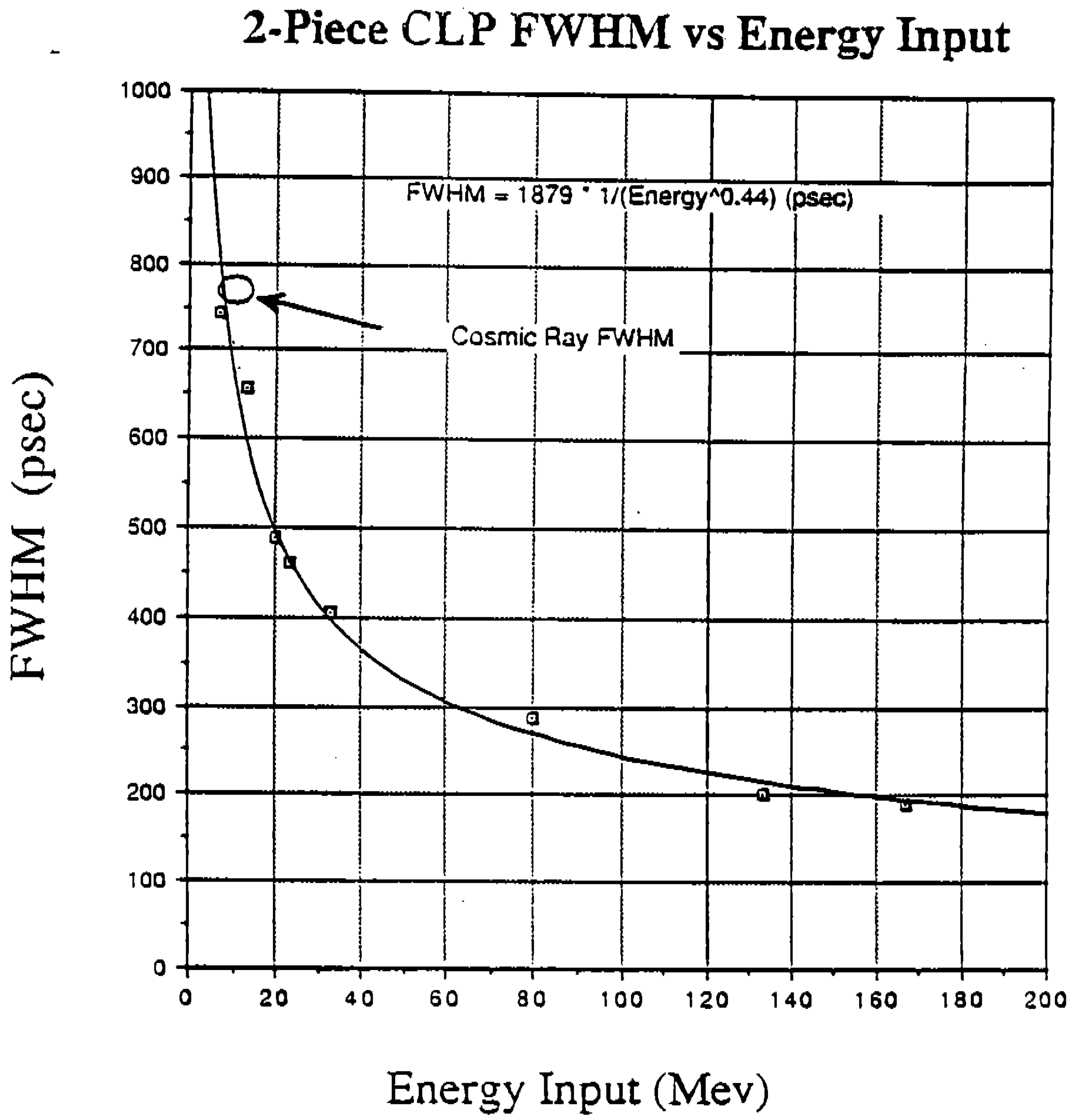

Figure 7: FWHM vs energy for 2-piece curved light guide..

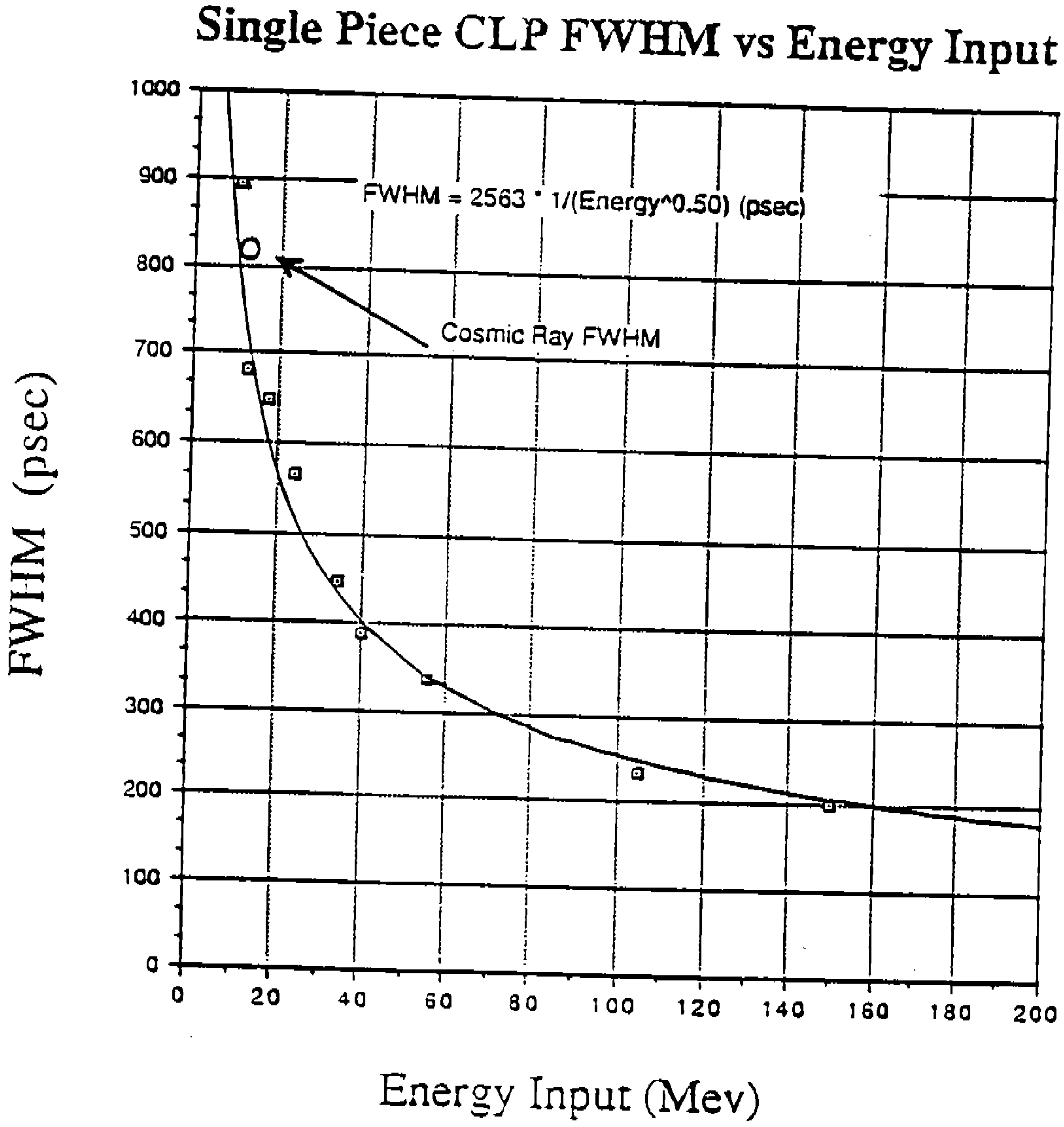

Figure 6: FWHM vs energy for single piece curved light guide.

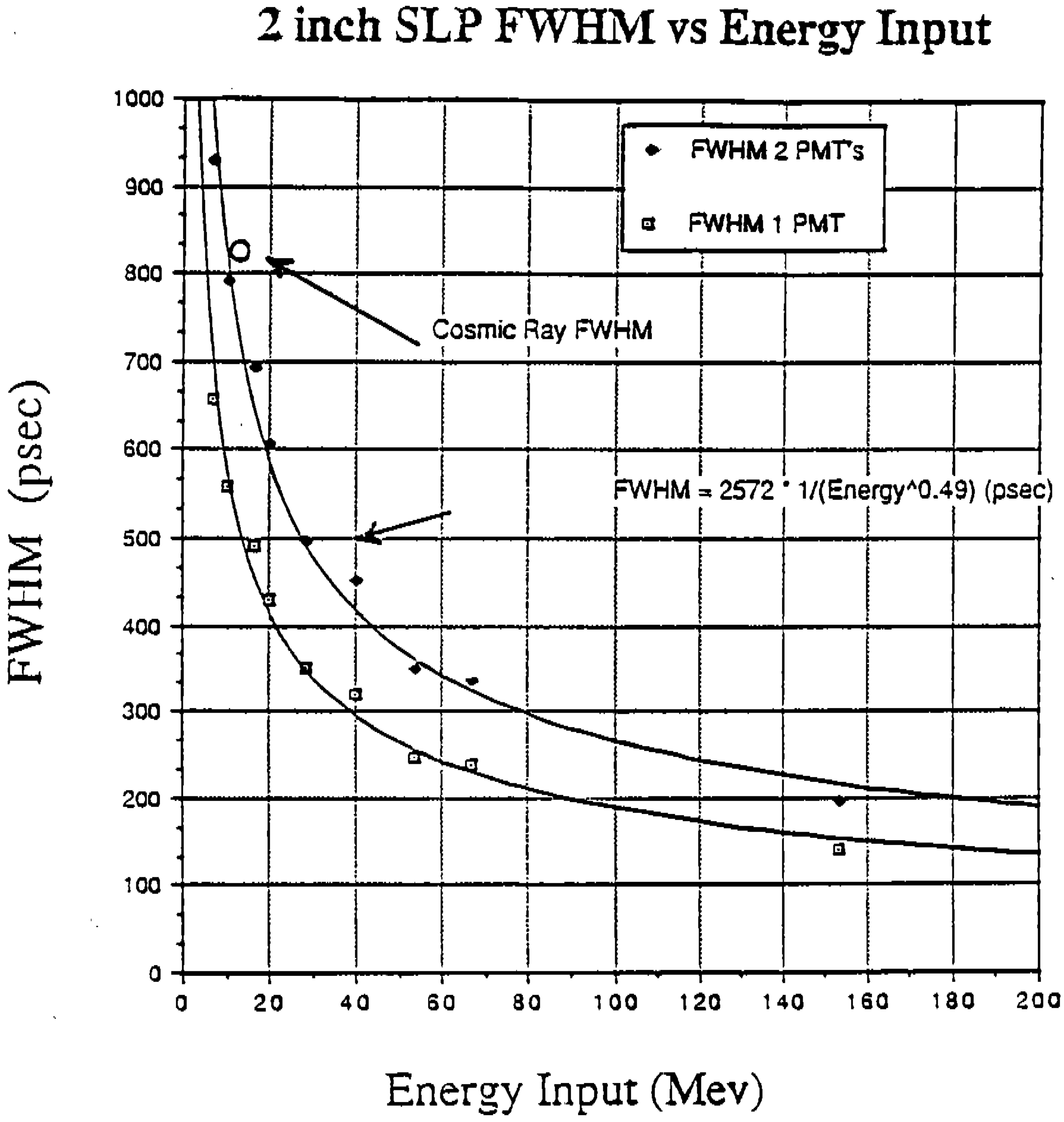

Figure 5: FWHM vs energy for straight light guides.

Table 2: Limits on the degradation of performance due to the light guide may be obtained by comparing the quadrature widths of the counter with one bent light guide to the same counter with two straight light guides. These values are taken at the equivalent light level for a minimum ionizing particle (10 MeV). The goal is to keep $\sigma_T \leq 161$ps for a $80 \times 20 \times 5cm^3$ counter.

Guide	*FWHM (ps)*	$\sigma_T(ps)$
straight	588	250
1-piece curved	557	237
2-piece curved	346	147
4-piece curved	475	202

4 Results and Conclusions

The results are summarized in Figures 5, 6, 7 and 8. The timing resolution is expected to be proportional to the inverse square root of the input energy because the response is dominated by photostatistics. As can be seen by the fitted curves, the data confirms this expectation, since the fitted exponents range from 0.45 to 0.51. The maximum error for each data point is of the order of twice the width of the data points. It is important to note that timing resolution at 10MeV shows a difference of over 100 ps between the four-piece and the two-piece LP and between the single piece and 2-piece LP. Table 2 gives the FWHM and corresponding r.m.s. contribution to the resolution due to the bent guide and associated PMT as determined from equation (6). Figure 9 is of some interest. As can be seen, the timing resolution for the 2" straight light pipe (SLP) is substantially better than the 2.25" SLP which was later bent to form a 1-piece curved guide . We attribute the abnormally poor timing resolution of the 2.25 SLP to bad coupling between the PMT and the light guide.

A few general conclusions may be reached from the data in Table 2 and summarized in Figure 10. All light guides had approximately the same time performance, $\sigma_T \sim 200$-250ps, albeit a factor of 40% worse than the goals set for the CLAS detector. The best design for timing cannot be extracted from the data because of systematic errors in the measurements, due primarily to the coupling between light guides and PMTs. The straight light guide,

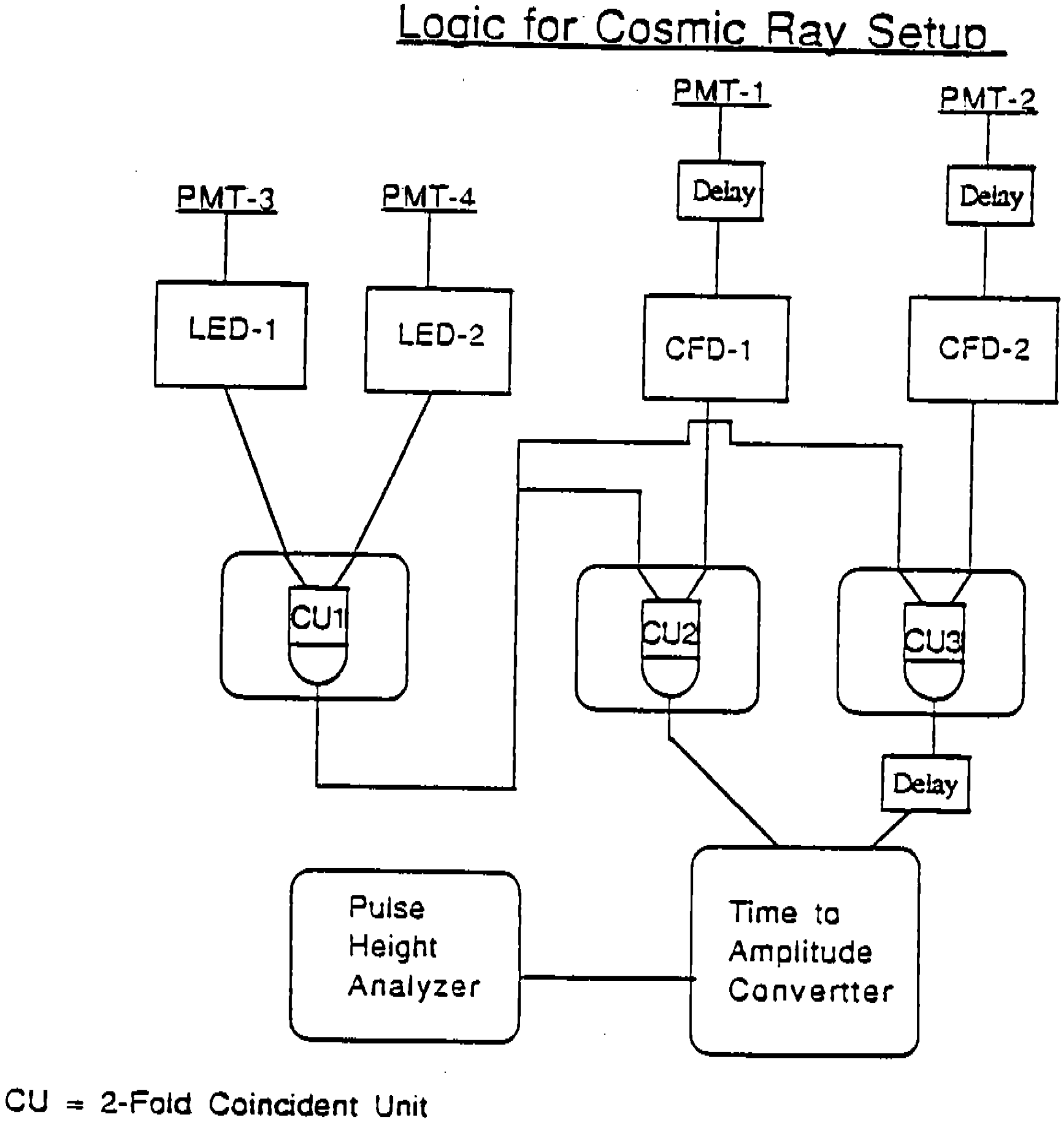

Figure 4: Logic diagram for measurements using cosmic rays.

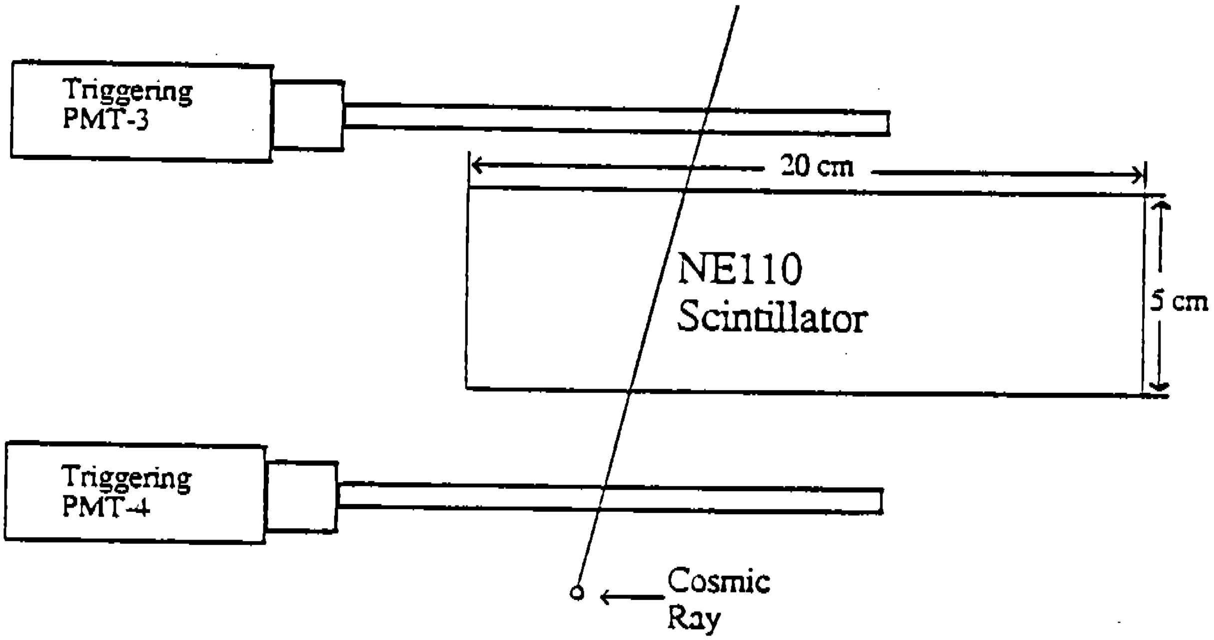

Figure 3: Setup for measurements using cosmic rays. The top trigger counter measured 2.5×15cm^2 and the bottom scintillator was 15×15cm^2.

3.2 Setup and Calibration

The different components of the counter shown in Figure 2 were calibrated in the following manner. The PMTs were tested against each other with a spark plug pulser (SPP) [4]. Both CFD and leading-edge discriminators were tested. Optimal timing was found with the CFD's set to -50mV, with a 5ns shaping cable. The PMT input voltage was plateaued for both PMT's and an optimal range was found between -1900V and -2300V. The tube input voltage was further optimized by insuring that both PMT output voltages were within 5% of each other as viewed on the oscilloscope. Input voltage for PMT-1 was set to -1900V and -2160V for PMT-2. The PMT's were shielded with a one layer mu-metal and by a soft iron tube. We note that XP2262 PMT's mounted in all plastic tubes with only a mu-metal shield were also tested for timing response but because of RF interference from a local radio station we were unable to achieve adequate timing results.

A Sr-90 source, which is a β^- emitter and has an end-point energy of 2.2 MeV, was used to calibrate PMT-2's output response. The calibration obtained this way was checked with cosmic-ray signals which correspond to 10 MeV of energy loss, assuming a shortest path length through the scintillator of 5 cm. By adjusting the light output of the PEK pulser, which was operated at 2000V and had a pulse rate of 60Hz, timing resolutions for each of the four light guides were obtained.

3.3 Cosmic-Ray Measurements

The timing resolution of each light guide was also tested with minimum ionizing cosmic-ray particles. Figure 4 shows the logic use in this setup. The thresholds of the two leading-edge discriminators used to to discriminate the pulses from PMT-3 and PMT-4 were set at -10mV and had a pulse width of 50ns. These tests were performed as consistency checks on the measurements with the pulser. The cosmic-ray measurements are systematically somewhat higher, but are within the experimental uncertainties. The results of these measurements are superimposed on pulser measurements shown in Figures 5–8 below. Furthermore, the cosmic-ray measurements contain a (small) contribution due to the widths of the trigger counters.

Table 1: Dimensions of light guides which were tested. All guides were tapered from 20cm, which was mated to the scintillator, down to the 5cm end which attached to a 5cm long, 5cm diameter acrylic cylinder which in turn was attached to the phototube.

Radius of Curvature	*Unbent Length(cm)*	*Thickness (cm)*	*Number of Pieces*
straight	42	5	1
23.8	43	5	1
23.8	42	5	2
23.8	42	6	4

function of energy deposited in the scintillator. We will refer to a scintillator with a PMT at each end as a counter. A PEK UV light pulser operated at 2000V, 60Hz and centered in the middle of the scintillator block was used as a light source. The two PMTs used were Philips XP2020's mounted in commercial tube bases.[3] Their outputs were fed into Ortec 415 Constant Fraction Discriminators (CFD). The output pulse of the first discriminator (CFD-1) was used to 'start' an Ortec Time-to-Amplitude 437 Converter (TAC) and the output pulse of the second discriminator (CFD-2) was delayed and used to 'stop' the same TAC. Output from the TAC, which was set to 50ns full range, was fed into a PCA-II multichannel analyzer card mounter in a 286 AT&T IBM compatible computer. The PCA was operated as a pulse height analyzer (PHA) and set for 2024 channels/10.0V full range which gave 24.7ps/channel.

To insure that there was minimal error in the testing of the light pipes (LP) only LP1 was replaced. LP2, which was straight, remained the same throughout. The LP's dimensions are listed in Table 1. On the end of each LP was glued a 5 cm long clear acrylic cylinder which was 5 cm in diameter. This provided optimal coupling between the phototube and the LP. The scintillator used was Nuclear Enterprise NE 110 and was 5 cm thick, 20 cm wide, and 80 cm long.

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[3] Products for Research Corporation PR1406RF.

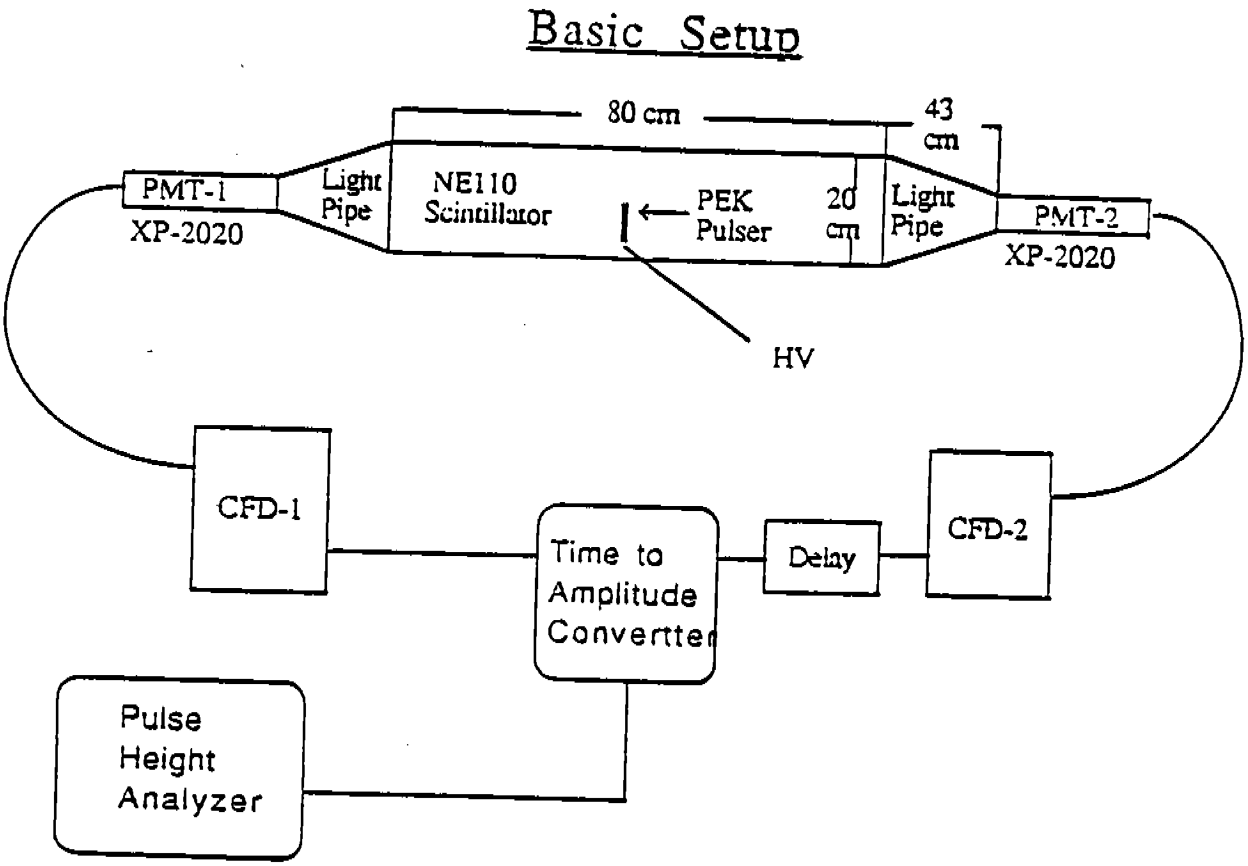

Figure 2: Setup for pulser measurements.

2 Procedure

We wish to consider the r.m.s. time resolution σ_c of a counter with a phototube at each end for actual particle initiated events. Let σ_{TA} and σ_{TB} be the r.m.s. resolutions observed for the two phototubes A and B at the ends of the piece of scintillator. Then

$$\sigma_c = \frac{1}{2}\sqrt{{\sigma_{TA}}^2 + {\sigma_{TB}}^2} \tag{1}$$

If the two phototubes contribute equally,

$$\sigma_c = \sigma_T/\sqrt{2} \tag{2}$$

The absolute time of the input signal is generally not known, but one can measure the time difference between the two phototubes. The distribution of this difference, for a point source, has a width twice the σ_c of (2) above:

$$\begin{aligned} \sigma_{diff} &= \sqrt{{\sigma_{TA}}^2 + {\sigma_{TB}}^2} && (3) \\ &= \sqrt{2}\sigma_T && (4) \end{aligned}$$

so that (2) and (4) give

$$\sigma_c = \sigma_{diff}/2 \tag{5}$$

We first measured the σ_{diff} for a counter with two similar unbent light guides. The resolution σ_T of a single phototube was obtained from (4). One of the two straight light guides was then replaced by the guide that was to be tested. The contribution of the new light guide, with its phototube and electronics was then obtained from (3):

$$\sigma_T(new\ guide) = \sqrt{{\sigma_{diff}}^2 - {\sigma_T}^2(straight\ guide)} \tag{6}$$

3 Evaluation of Light Guides

3.1 Experimental Setup

Figure 2 shows the basic setup that was used to test the light guides as a

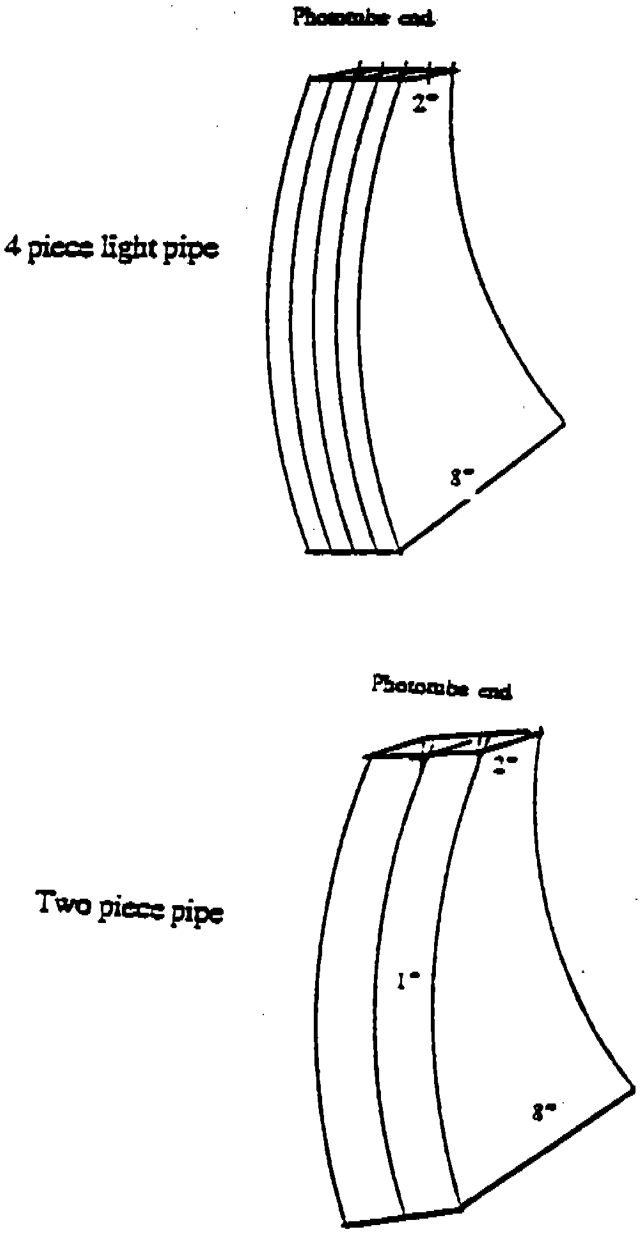

Figure 1: The figures show how the curved light guides are built up from layers of acrylic sheets.

1 Overview

The geometry of the CLAS detector [1] leaves approximately 30cm of space in the shadow of the coils at the ends of the time-of-flight (TOF) scintillators. In order to cover the active region of the detector with scintillators, the light guides and the photomultiplier tube (PMT) and base assemblies must fit into this shadow region. Large-area coverage with scintillators with good time resolution has been achieved best with 2" PMT's and 5cm thick scintillator with large attenuation length ($\geq$ 400cm). Straight triangular light guides, 5cm thick which tapper from the width of the scintillator down to the PMT would have to have a length of less than 12cm in order to fit the entire assembly into the allocated space. In addition, because the magnetic field lines would be aligned with the PMT, this configuration is difficult to shield magnetically. Given these constraints, we have investigated the possibility of using light guides which are bent out of the plane of the scintillator.

The timing properties of bent acrylic light guides have been investigated previously. Some of the earliest work was done by Massam [2]. He concluded that if the ratio of the bend radius was less than one tenth of the thickness of acrylic, then less than 4% of light is lost in the bend. Light guides made of thin sheets were used by a collider experiment at Fermilab [3]. Guides with a 90^o bend were made out of seven lucite sheets each. These guides did not noticeably decrease the excellent timing resolution of their system. The shop at William and Mary has built guides of one, two and four sheets to study the construction process of this type of light guide. Generally, the fewer number of pieces used, the less time consumed and simpler the fabrication. Schematic views of the assembly of these light guides are shown in Figure 1.

The design goals of the TOF system are to achieve root-mean-squared (r.m.s.) timing resolutions of 120ps for the smallest counters and 180ps for the largest. Each counter will have one PMT mounted on each end, so the contribution of each PMT is 170ps or 255ps respectively. This corresponds to FWHM measurements of 400 and 600ps for a individual PMTs.

List of Figures