STAR NOTE 267

STUDIES OF RUSSIAN MESH DYNODE PHOTOMULTIPLIER TUBES

S. Ahmad and M. Morgan
Rice University

ABSTRACT

Tests have been made to evaluate the performance of Russian manufactured close proximity mesh dynode photomultiplier tubes. These tubes have been compared with a similar Hamamatsu R5505 tube for possible use in the Time of Flight (TOF) subsystem of the Solenoidal Tracking at RHIC (STAR) project. Gain and timing characteristics of these tubes have been tested inside and outside a magnetic field using a N_2 ultraviolet laser.

Introduction

The TOF subsystem of STAR consists of a barrel-shaped array of several thousand scintillators coupled with photomultipliers. Because the experiment takes place in a 5 kG magnetic field parallel to the beam, these photomultipliers must maintain satisfactory performance in the field. Hamamatsu is the only manufacturer with models that meet this requirement. Work has been underway by a Russian manufacturer to develop similarly capable tubes for this project. The Russian maker has built several prototypes. These prototypes have been evaluated by comparison with a Hamamatsu tube.

Laser System

A VSL-337ND N_2 plasma laser producing 3 ns wide pulses of 337 nm UV light was used. This laser is manufactured by Laser Science, Inc. The laser has a maximum trigger rate of 20 Hz by either an internal or an external trigger. It was operated at approximately 3 Hz by an external trigger for the present tests.

Light from the laser is first focused with a quartz lens onto the face of an 800 micron silica fiber. The distance between the lens and fiber face was adjusted to maximize light collection at the other end of the fiber. The light is then routed through two stages of splitter boxes to distribute the light among 20 fibers at each stage. Each splitter box uses a lens to focus light from a single input fiber onto a close-packed bundle of smaller fibers. In the first stage a bundle of twenty 200 micron fibers is used. In the second stage, the bundle is made of twenty 100 micron fibers. Connectors place the face of the bundle fiber within 2 or 3 mm of the connecting fiber. Thin sheets of mylar absorbers were placed between the input fiber and the focusing lens in the second box to control the intensity. The absorbers were adjusted to produce a response in an aluminum-wrapped 4 cm x 4 cm x 1 cm piece of BC404 scintillator equal to the response from a 1 MIP particle passing through the center of a typical TOF scintillator. From the second splitter box, light is sent to the BC404 test scintillator that has been connected to the test phototube. An RCA 8575 phototube was also connected to one of the output fibers from the second box and was used as a monitor. The fiber tip was held at the glass surface of the RCA 8575. This monitor tube was operated at 2100 V for all tests.

Experimental Setup

We have tested two batches of Russian tubes. The first batch consisted of R1N2 and R2N4. The second batch included tubes #17, #29, #32, #38, #39, #47, #48, and #58. The performances of these tubes were compared with a Hamamatsu R5505 tube. Figure 1 shows the electronics used for all tests. The pulses from the RCA 8575 monitor phototube and the phototube system being tested were sent to LeCroy NIM discriminators. For timing, discriminated signals were sent to a Phillips 7186 TDC CAMAC module which has 25 ps per channel resolution. Analog signals were recorded by a LeCroy 2249A CAMAC ADC. The pulses from the monitor phototube were used to generate the start for the TDC. The TDC was stopped on the discriminator pulses from the phototubes being tested. The data were then read and analyzed using the Kmax software package running on a Macintosh computer. For gain measurements, pedestal subtracted ADC values from the test photomultiplier system were divided by corresponding values from the monitor tube to provide a measure of relative gain. This method was selected to normalize for variations in intensity among individual laser pulses. Timing and gain data were histogrammed using the Kmax package.

Photocathode Uniformity

Photocathode mapping was done for a Hamamatsu R5505 and all the Russian prototype tubes except #47 which had no photocathode upon delivery. Figure 2 is a diagram of the setup used for photocathode mapping. A laser fiber was held perpendicularly within 2 mm of each test phototube glass envelope to directly excite the photocathode. One set of tests was made illuminating areas 3 mm from the center of the photocathode spaced every 45 degrees. Another set was made by illuminating points 0 mm, 3 mm, and 6 mm from the photocathode center. The ADC signals from the tubes were divided by the corresponding RCA 8575 monitor signals to give a measure of gain at each area of illumination. For the second set, the 3 mm and 6 mm points were first averaged to give a mean gain for each radius. For each test, the angular and radial RMS deviations in gain were found for each tube. Table 1 shows these deviations. Figures 3 and 4 show gain versus angle plots for the Hamamatsu R5505 and the Russian R2N4, respectively, whereas Figures 5 and 6 show radial photocathode mapping for these tubes. The R2N4 has photocathode uniformity comparable to that of the Hamamatsu R5505.

Table 1: Photocathode Mapping

Photomultiplier	**Angular Deviation**	**Radial Deviation**
Hamamatsu R5505	3.7%	5.7%
Russian R1N2	24%	16%
Russian R2N4	6.5%	5.5%
Russian #17	8.7%	10%
Russian #29	27%	33%
Russian #32	19%	11%
Russian #38	26%	17%
Russian #39	8.4%	13%
Russian #47	N/A	N/A
Russian #48	12%	7.6%
Russian #58	11%	16%

Gain Studies

A 4 cm x 4 cm x 1 cm piece of aluminum-wrapped Bicron BC404 scintillator was used in the following tests. Laser light was injected at the center of a 4 cm x 1 cm surface as shown in Figure 7. The photomultipliers were coupled with optical grease to a 4 cm x 4 cm face. The laser intensity was chosen to produce 1 MIP as described previously. Because of extremely low gain, further testing of the Russian tube #29 was discontinued.

The variation of gain with voltage was measured for the Russian tubes, except #29 and #47, and a Hamamatsu R5505. The ADC signal was recorded as described previously while varying the high voltage. The attached plots Figures 8 and 9 summarize the gain results for the first and second batches of Russian tubes, respectively, compared to the Hamamatsu R5505. For the same gain, the Russian tubes show a large variation in operating voltages which makes selecting an operating voltage for further operation difficult.

Gain versus Magnetic Field

The gain variation of the photomultiplier tubes in a magnetic field was also measured. As shown in Figure 7, the phototubes were suspended between the poles of a magnet by an aluminum rod. The rod was constructed to rotate the tube between the magnet poles with a fixed protractor used for angular alignment. The tubes were tested in 0, 1, 2, 3, 4, and 5 kG magnetic fields. The tubes were rotated to angles of 0, 10, 20, 30, and 40 degrees with respect to the tube axis and the direction of the magnetic field. At each of these points, the signal was read using the ADC and divided by the monitor signal as a measure of gain at a particular field strength and orientation.

From the previous zero magnetic field tests of gain variation versus voltage, operating voltages for each tube were selected. In a 5 kG magnetic field, the Russian tubes experienced a gain drop approximately one to three times greater than the gain drop found with the Hamamatsu R5505. For this reason, Russian tubes were operated at a voltage such that the gain performance in 5 kG would be similar for all tubes.

The large casing of the Russian tube #48 prevented any further testing in the magnetic field. Also, tube #58 apparently lost its photocathode due to a leak around the pins. No further testing in the magnetic field was done with the Russian tube R1N2 because of its poor photocathode mapping. Figures 10, 11, 12, 13, 14, and 15 show gain versus magnetic field plots for Russian tubes #17, #32, #38, #39, R2N4, and Hamamatsu R5505, respectively. Data points at different angles are denoted by different symbols. The gains have all been normalized to the zero field Hamamatsu gain. These figures show performance variations among the tubes. The performance of tube #17 is similar to R2N4 (shown in Figure 14), and at 5 kG, the performances of tubes #17 and R2N4 are comparable to Hamamatsu R5505 as shown in Figure 15. For these two tubes, selecting an initial no field gain three times greater than the Hamamatsu R5505 results in similar gain performance in the 5 kG field. The gain versus angle plot at 5 kG for the R2N4 and the Hamamatsu R5505 is shown in Figure 16, whereas Figures 17, 18, 19, and 20 show the gain for the other Russian tubes. The Russian tube #17 and R2N4 perform similarly to the Hamamatsu R5505. Other tubes, however, perform worse. There may be some correlation between photocathode uniformity and magnetic field performance, but using such a small sample of tubes is not conclusive.

Time Resolution

Timing resolution for the Hamamatsu R5505 and the Russian prototype phototubes R2N4, #17, #32, #38, and #39 was measured in 0 and 5 kG magnetic fields. The experimental arrangement used remained the same as for the magnetic gain tests. A 1 MIP light pulse was used to illuminate the BC404 scintillator as described earlier. The tubes were rotated through angles from 0 to 40 degrees by 5 degree intervals. For these measurements, as mentioned earlier, the RCA 8575 monitor tube was used to start the Phillips 7186 TDC, and the TDC was stopped by the test phototube. The resolution results were then corrected for time jitter resulting from the monitor photomultiplier tube. The timing resolution for each test system of scintillator and photomultiplier was thus obtained using the following formula:

$$\sigma = \mathrm{sqrt}\,(\,\sigma^2_{\mathrm{measured}} - \sigma^2_{\mathrm{monitor}}\,)$$

with

$$\sigma_{monitor} = 45 \text{ ps}$$

Tables 2 and 3 summarize the resolution measurements. Because the Hamamatsu R5505 has a smaller photocathode area, its timing results have been normalized by the square root of the ratio of photocathode areas between the Hamamatsu and Russian photomultiplier tubes. The timing resolution versus angle in a 5 kG magnetic field is plotted in Figures 21, 22, and 23. Results are comparable to the Hamamatsu for Russian tubes #17, #38, and R2N4, but not for #32 and #39. Again, there may be some correlation between photocathode uniformity and timing performance; however, using such a small sample is not conclusive.

Table 2: Timing Results for a Hamamatsu R5505 and Russian R2N4 in a 5 kG Magnetic Field

B (kG)	Angle (degrees)	σ (ps)		
		Hamamatsu R5505	Normalized Hamamatsu	Russian R2N4
0	0	66	58	72
5	0	122	107	112
5	5	108	95	109
5	10	111	97	95
5	15	111	97	98
5	20	113	99	98
5	25	103	91	111
5	30	128	112	126
5	35	128	112	136

B is the magnetic field in kG.
Angle is the angle between the magnetic field and the axes of the tubes.
BC404 (4 cm x 4 cm x 1 cm) was used in these tests.
Normalized Hamamatsu has been corrected by the square root of the area ratio between Russian and Hamamatsu tubes.

Table 3: Timing Results for Hamamatsu R5505 and Russian PMT's in a Magnetic Field							
B (kG)	Angle (degrees)	σ (ps)					
		Russian #17 @ 1300 V	Russian #32 @1600 V	Russian #38 @1700 V	Russian #39 @ 1050 V	Hamamatsu @ 2100 V	Normalized Hamamatsu
0	0	68	78	89	66	79	69
5	0	100	118	93	80	106	93
5	5	83	145	100	65		
5	10	100	139	88	81	109	96
5	15	100	130	104	89	105	92
5	20	100	130	96	93	109	96
5	25	104	130	125	76		
5	30	108	146	119	90	109	95
5	35	114	146	187	103		
B is the magnetic field in kG. Angle is the angle between the magnetic field and the axes of the tubes. BC404 (4 cm x 4 cm x 1 cm) was used in these tests. Normalized Hamamatsu has been corrected by the square root of the area ratio between Russian and Hamamatsu tubes.							

Conclusions and Recommendations

A shorter envelope should be used for the Russian tubes. The present casing makes the tubes larger than necessary and more difficult to test inside the magnet. The pins of the envelope must also be standardized. Currently, base construction is difficult because the pin spacing varies slightly among the prototypes. A more standard design would allow for socketed bases to be easily used.

Several of the Russian tubes perform similarly to the Hamamatsu in photocathode uniformity, gain, and timing resolution, but other prototypes do not. More uniform performance among the tubes is needed. More uniform photocathodes would probably give better gain and timing performance. Tubes with more uniform photocathodes tended to perform better in tests. Gain standardization is also necessary in future tubes. The voltages necessary to obtain similar gain varied widely by several hundred volts among the tubes. The gain characteristics in a magnetic field must become standard among the tubes. Timing resolution also varies among the tubes and probably corresponds to photocathode uniformity. Another related issue is reliability of the tubes. We feel that care must be taken to maintain better uniformity and reliability of the tubes.

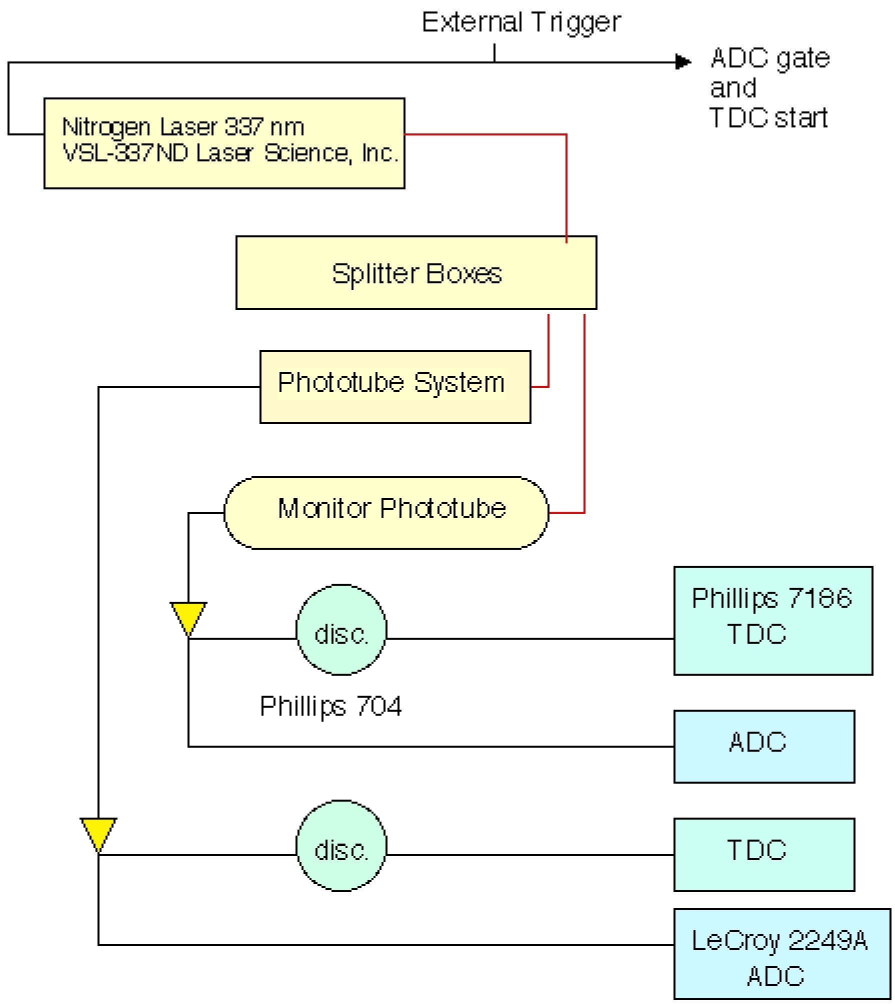

Fig. 1. Schematic of the Electronics

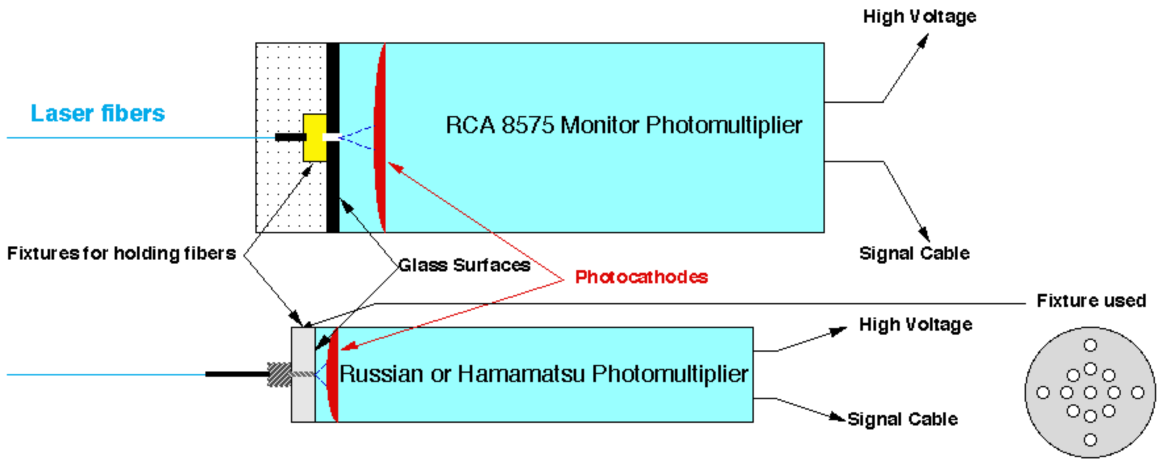

Fig. 2. Experimental Arrangement

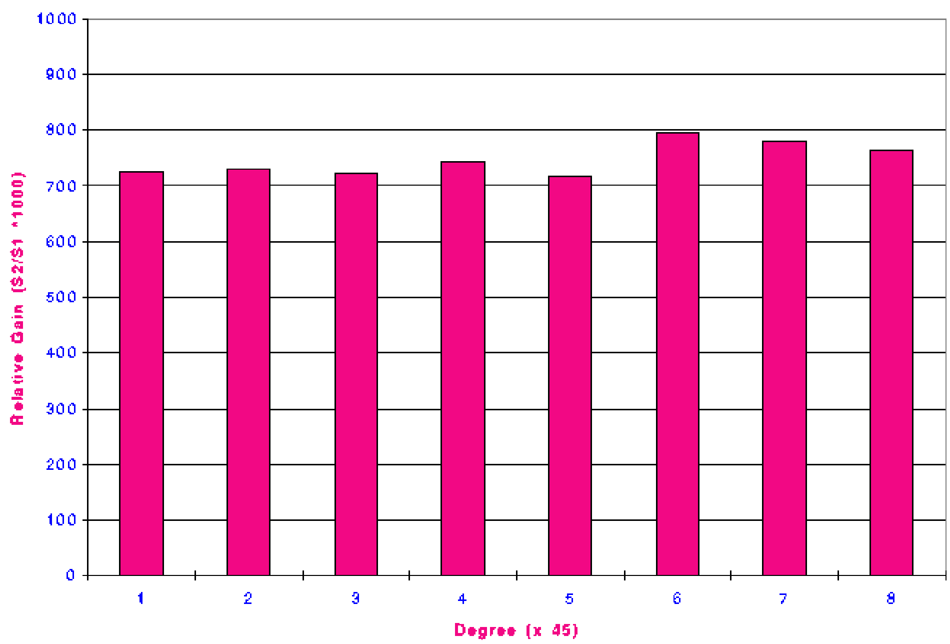

Fig. 3. Angular Photocathode Mapping for Hamamatsu R5505

3.8% area illuminated for each point.

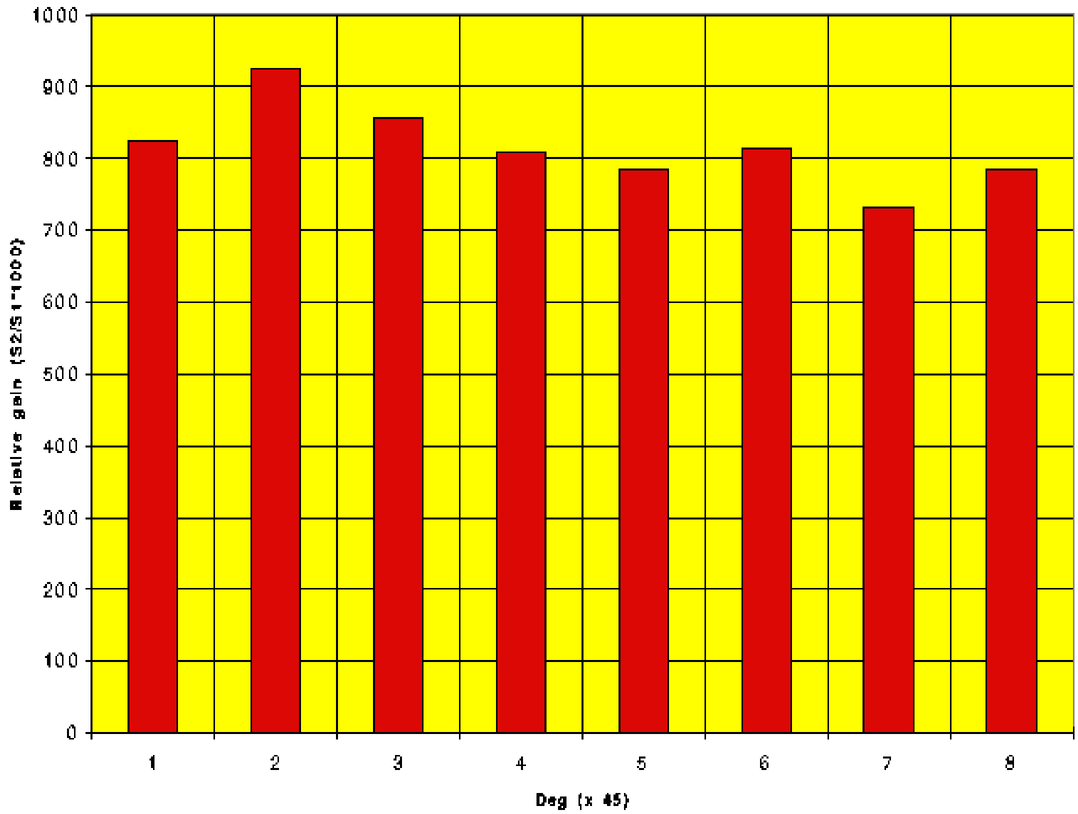

Fig. 4. Angular Photocathode Mapping for Russian R2N4
3.2% area illuminated for each point.

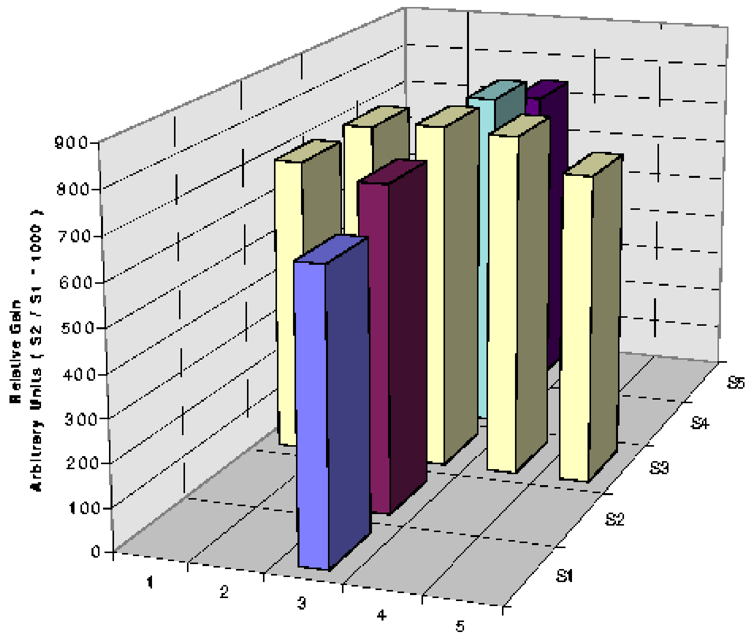

Fig. 5. Radial Photocathode Mapping for Hamamatsu R5505

(3.8% of photocathode area illuminated)

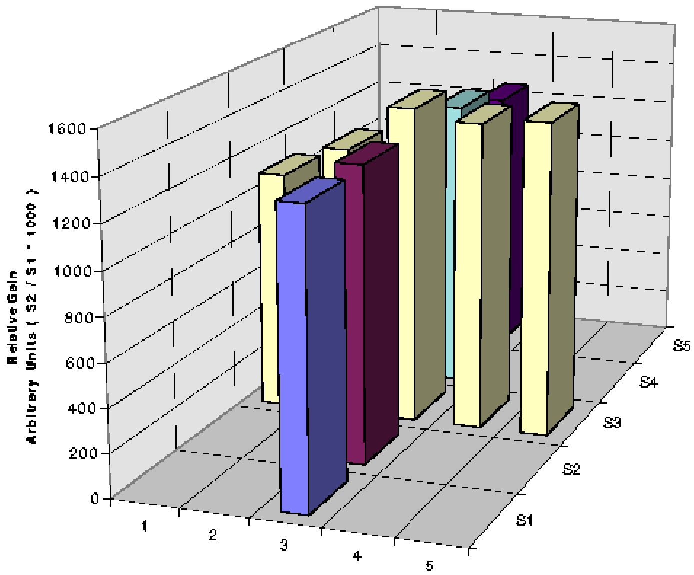

Fig. 6. Radial Photocathode Mapping for Russian R2N4

(3.2% of photocathode area illuminated)

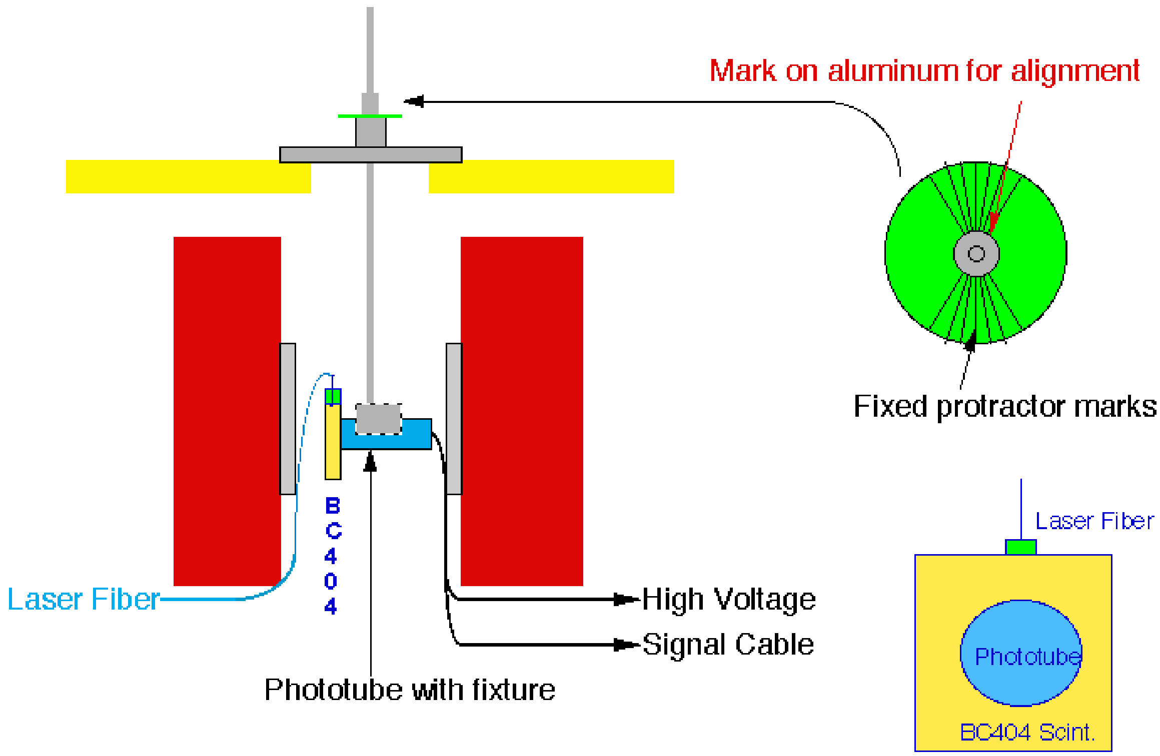

Fig. 7. Experimental Arrangement for Magnet Tests

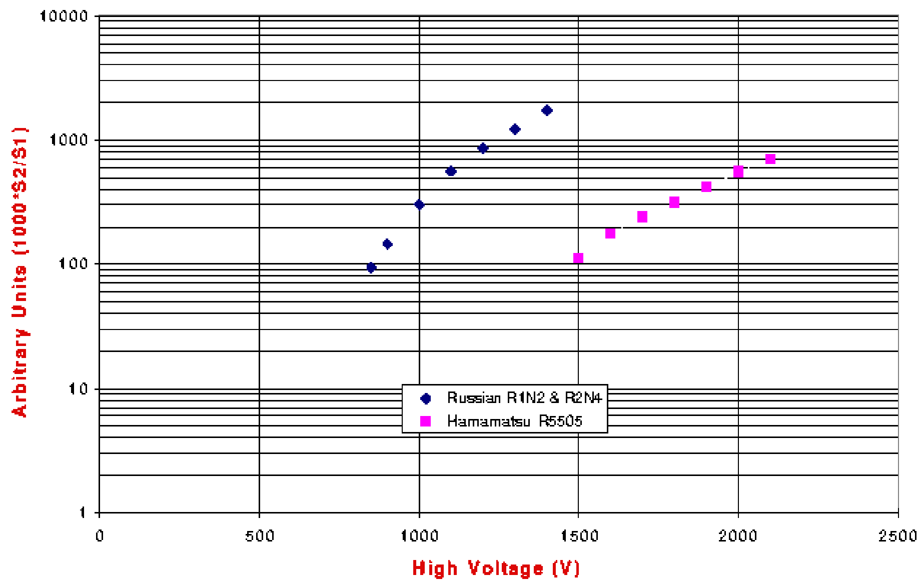

Fig. 8. Gain versus High Voltage

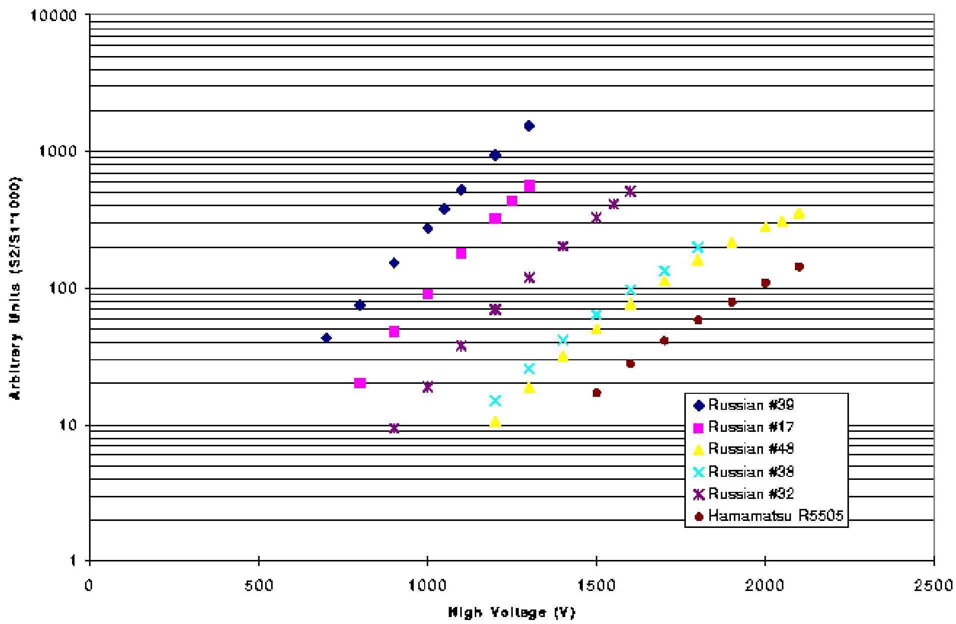

Fig. 9. Gain versus High Voltage

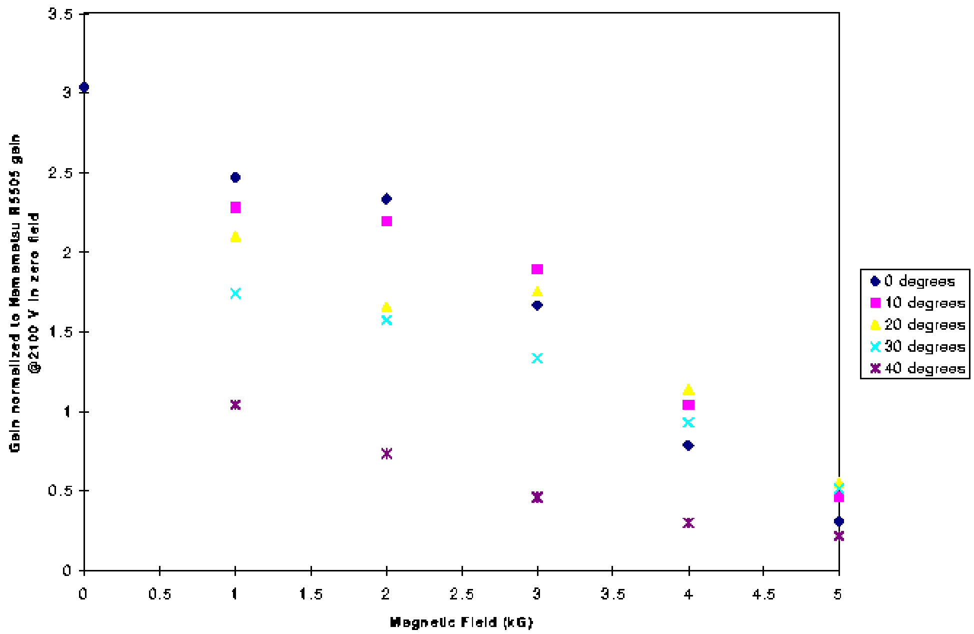

Fig. 10. Gain versus Magnetic Field and Angle for Russian PMT #17 @1250 V

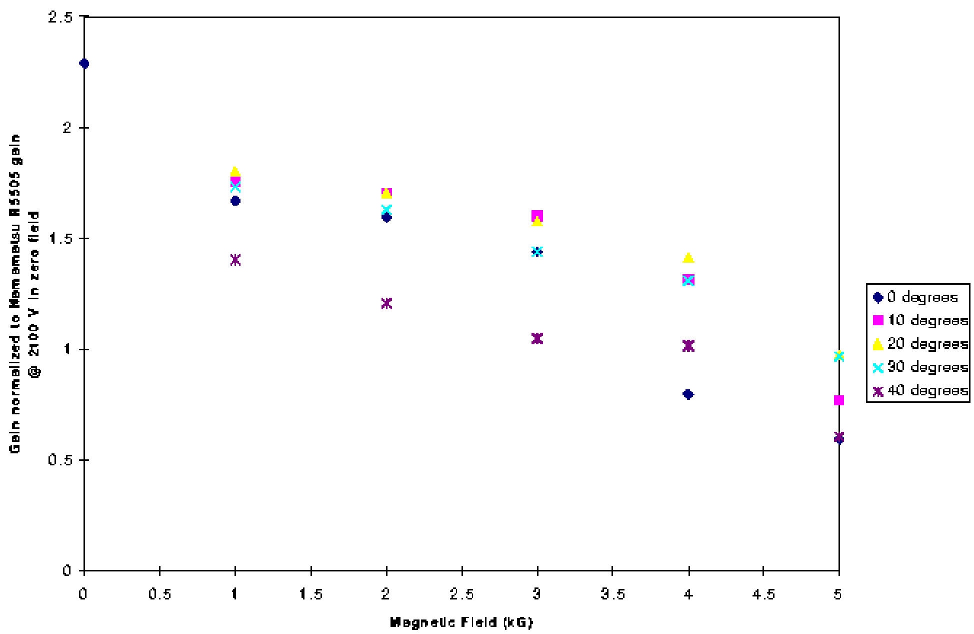

Fig. 11. Gain versus Magnetic Field and Angle for Russian PMT #32 @1500 V

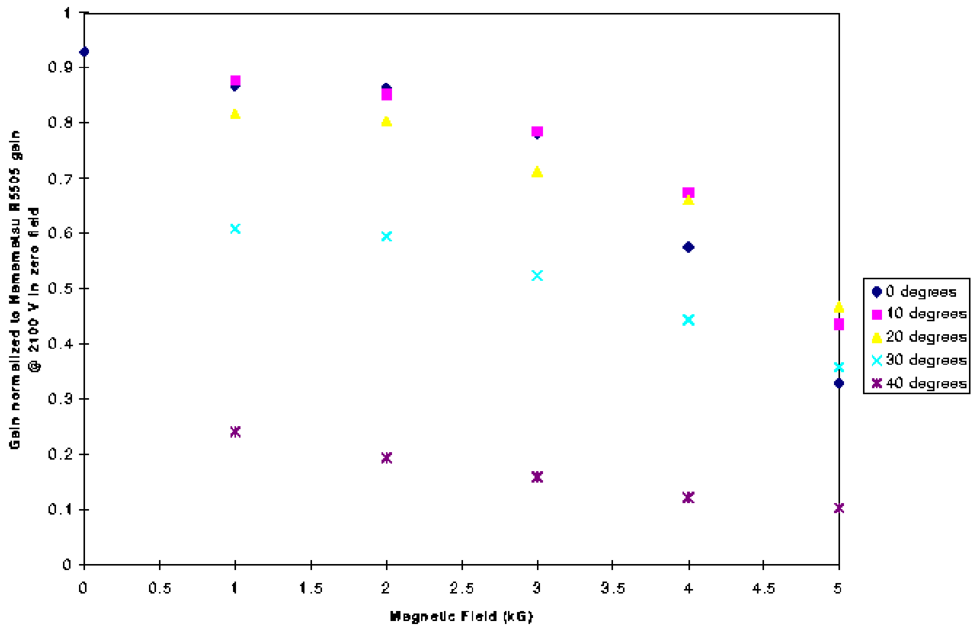

Fig. 12. Gain versus Magnetic Field and Angle for Russian PMT #38 @ 1700 V

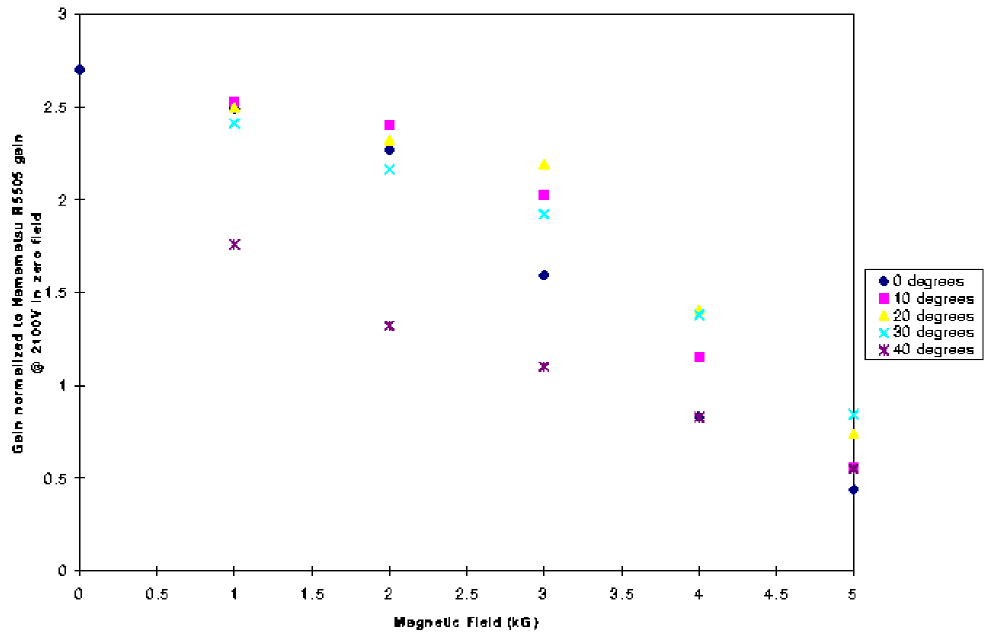

Fig. 13. Gain versus Magnetic Field and Angle for Russian PMT #39 @ 1050 V

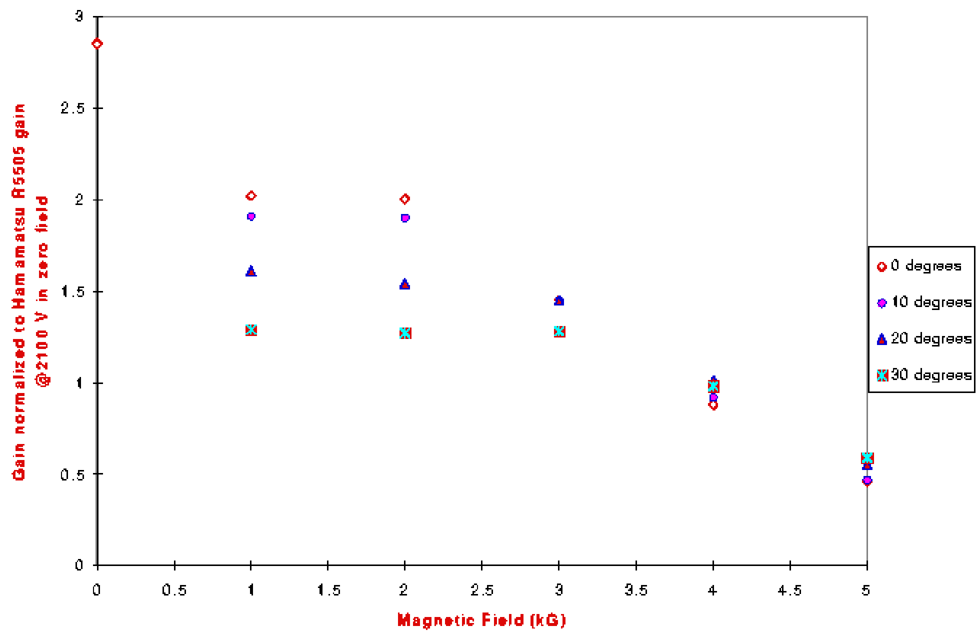

Fig. 14. Gain versus Magnetic Field and Angle for Russian PMT R2N4

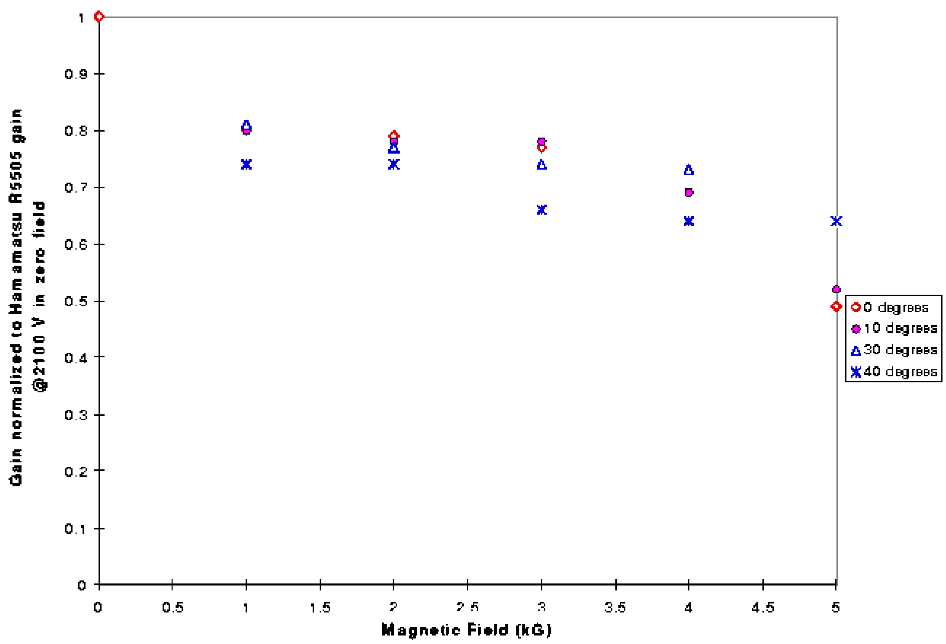

Fig. 15. Gain versus Magnetic Field and Angle for Hamamatsu R5505

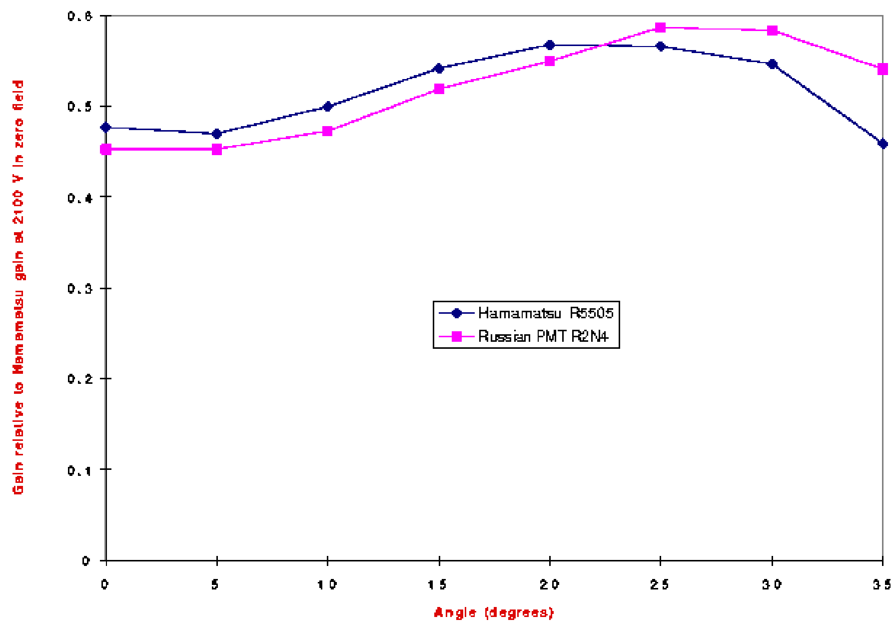

Fig. 16. Gain versus Angle in 5 kG Magnetic Field

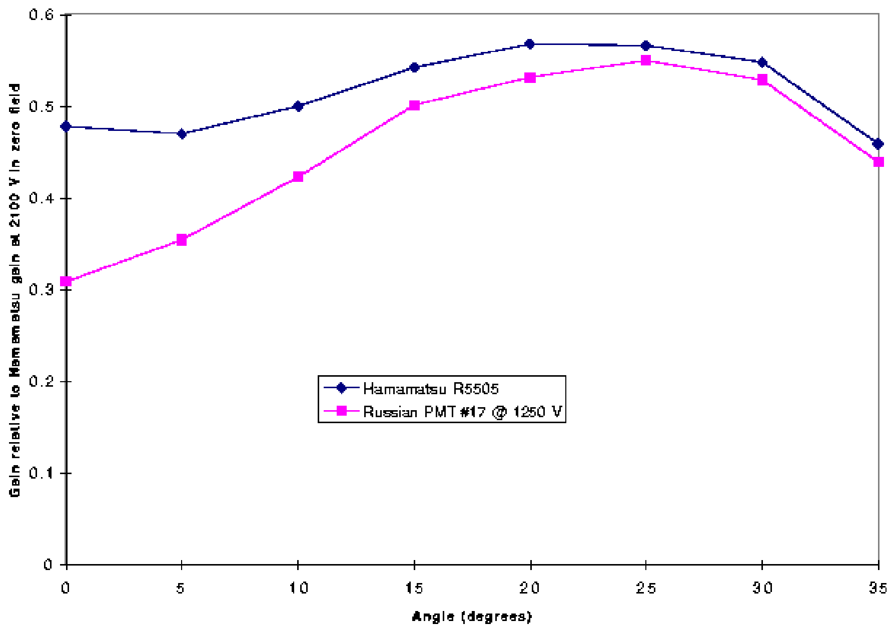

Fig. 17. Gain versus Angle in 5 kG Magnetic Field

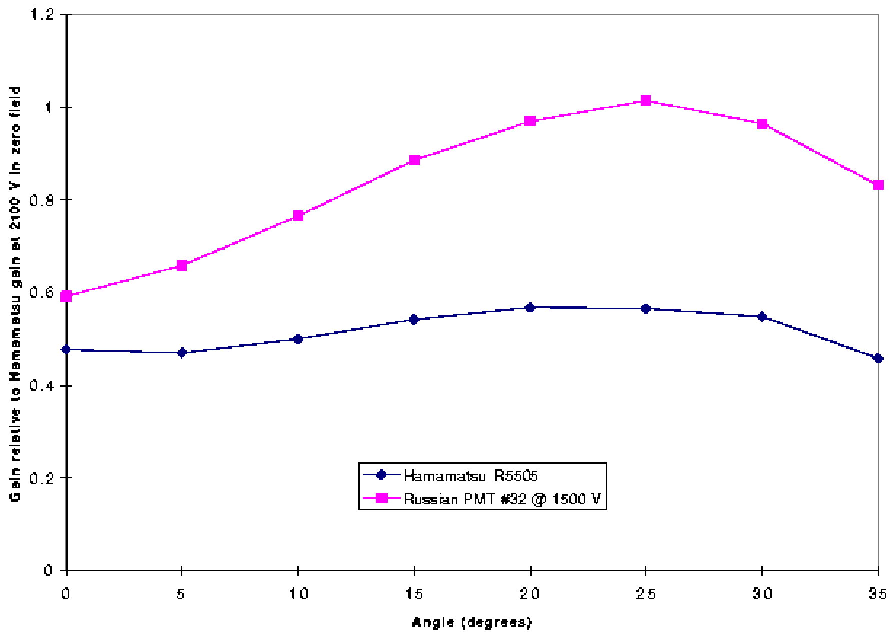

Fig. 18. Gain versus Angle in 5 kG Magnetic Field

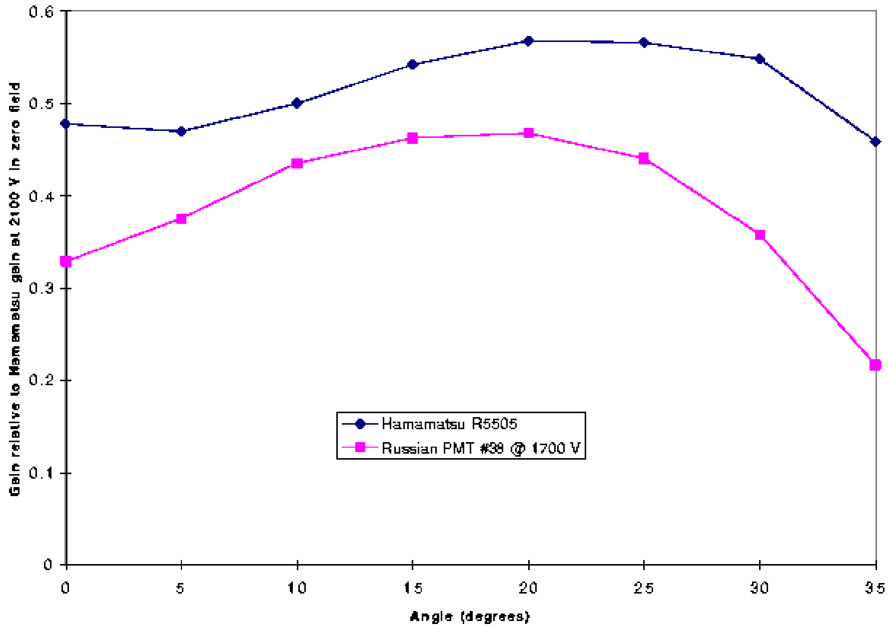

Fig. 19. Gain versus Angle in 5 kG Magnetic Field

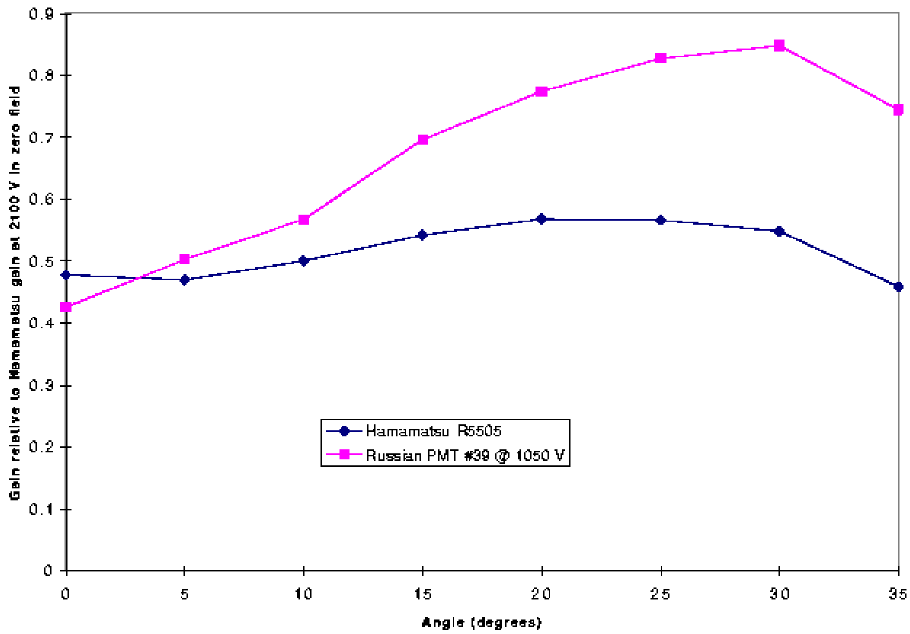

Fig. 20. Gain versus Angle in 5 kG Magnetic Field

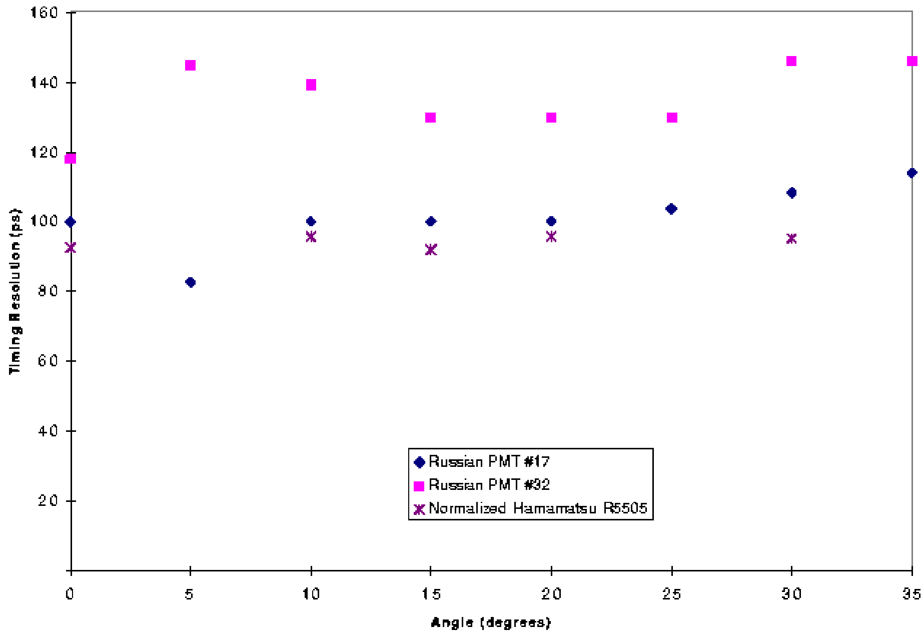

Fig. 21. Timing Resolution versus Angle in 5 kG Magnetic Field

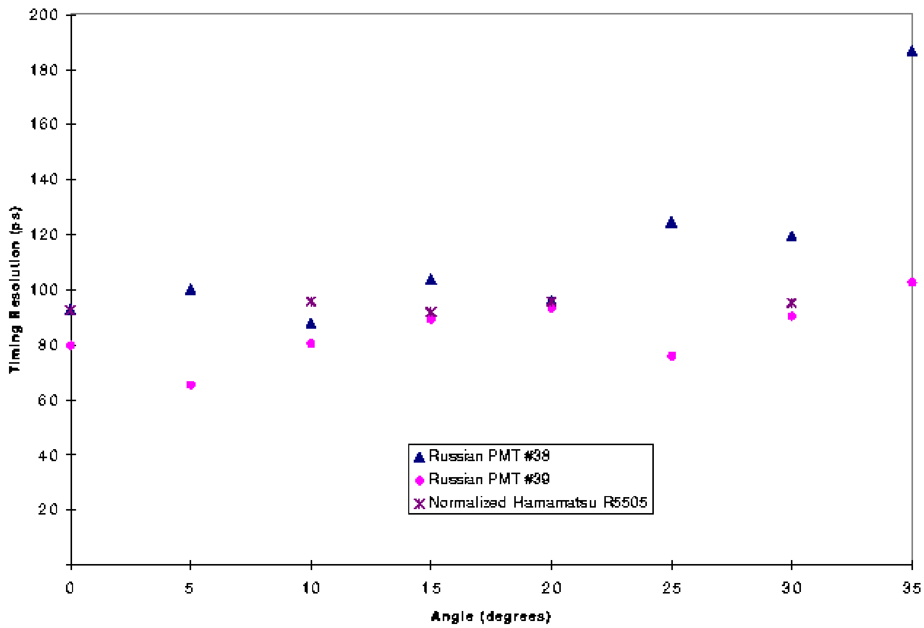

Fig. 22. Timing Resolution versus Angle in 5 kG Magnetic Field

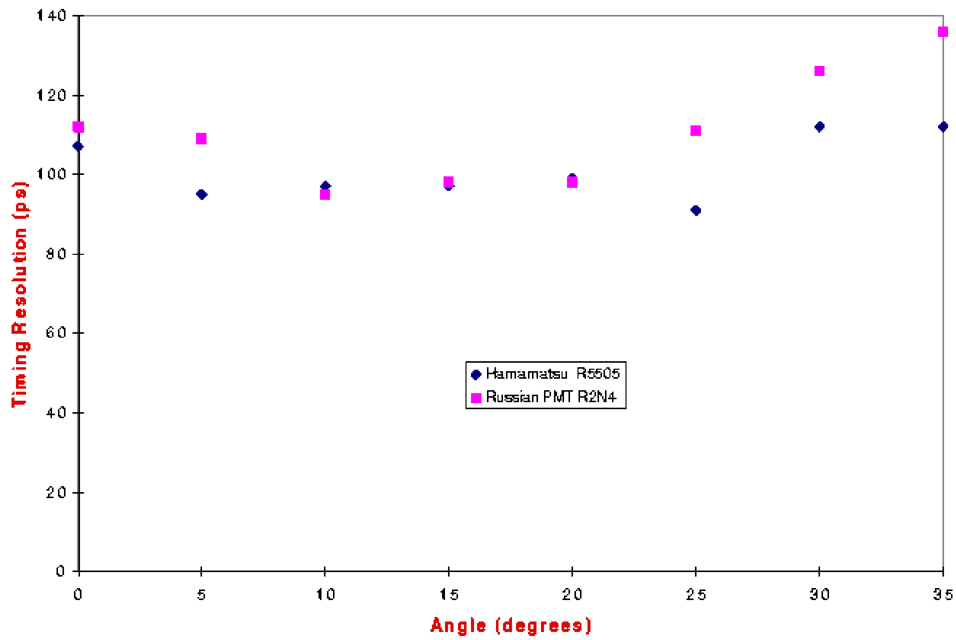

Fig. 23. Timing Resolution versus Angle in 5 kG Magnetic Field