Tests of Phillips XP4312B/D1 PMT in Magnetic Field

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We have measured the pulse height and time response of the 3" Philips XP4312B/D1 [2] photomultiplier tubes (PMTs) in magnetic fields up to 44 G. These PMTs will be used to detect light at each end of the large-angle scintillation counters of the CLAS time-of-flight system [1]. The calculated magnetic field at the position of the PMTs is shown in Figure 1 as a function of scattering angle, which determines the position of a particular TOF scintillator. The maximum field expected is 25 G, depending on the actual location of the PMT.

1 Procedure

The PMT, surrounded by a cylindrical μ-metal shield, was placed inside a dark box, which was situated between two Helmholtz coils (Figure 2). The magnetic field inside the dark box could be adjusted by changing the current in the coils, and provided a uniform field at the location of the PMT. The field at the location of the PMT (18.8 ± 0.1 G) was measured with a gauss meter for a current in the coils of 30 A. Fields at other current settings were assumed to be proportional, as determined by previous measurements in that same setup [3]. The effect of cables, connectors and all other materials in the dark box –except the μ-metal shield– was below the sensitivity of the gauss meter (0.1 G).

Seven LED's were uniformly spaced along a line and placed on a disc with matching holes. The hole spacing was 10 mm and their diameter was 8 mm. LED number 4 was at the center of the PMT. The disc fit into the μ-metal shield and placed up against the face of the PMT. The row of LEDs thereby spaned a diameter of the PMT. The disc could be moved with the PMT along the axis of the shield or rotated so the LED's illuminated a different diameter of the PMT. See Figure 2.

A single LED was fired at a time with a LeCroy 9210 pulse generator providing a +8 V pulse, 6 ns wide with 4.5 ns rise and fall times, at a frequency of 15o Hz. The pulser fired one LED at a time. This also provided a TDC start and ADC gate. The PMT pulse was passively split. One third of the pulse was fed into an LeCroy 2249 ADC, the other two thirds was discriminated with a Phillips 705 Constant-fraction discriminator (CFD) and used as stop of a LeCroy 2228A TDC (set at 50 ps/count). A typical time jitter at a fixed position on the PMT, as determined by the widths of the TDC distributions, was $\sigma \sim 200$ ns. The jitter is presumably due to the time variations of the LED response to the pulser. The mean time at each LED position, however, could be determined statistically much more accurately, but reproducible to about 100 ps. At each setting, determined by the position of the LED and the magnetic field, the pulse height on the oscilloscope, the ADC and TDC of the PMT were recorded.

2 Data

Four sets of data were taken, as summarized in Table 1. The first (Figures 4 and 5) and fourth (Figures 6 and 7) data sets determined the effect of an external field on the PMT shielded by two different cylindrical shields. The second set (Figure 8) measured the response of the PMT at zero field for different orientations of the LEDs. The third set (Figure 12) determined the PMT response as a function of the distance of the PMT window to the edge of the μ-metal shield. In all cases, the direction of the external magnetic field was perpendicular to the PMT and approximately along the direction connecting the anode and cathode pins of the socket (see Figure 9).

2.1 Systematics

The measurements in the magnetic field were accomplished by firing seven LEDs placed along the window of the PMT. This scheme was easily implemented without the use of magnetic materials which could distort the fields

Table 1: Configuration of data sets. The μ-metal shields were both 1mm (0.040") thick. The 11"-long shield was 3.325" inner diameter, the 8"-long shield was 3.25" in diameter (Magnetic Shield Corporation 32P80).

Parameter	*Set 1*	*Set 2*	*Set 3*	*Set 4*
μ-metallength	11"	11"	11"	8"
Magnetic Field	variable	off	18.8 G	variable
Window to μ-metal edge	3.4"	3.4"	variable	1.4"
LED orientation	3 o'clock	variable	9 o'clock	9 o'clock

in the vecinity of the PMT. However, a drawback to this method is that the measurements at different positions across the face of the PMT are made with different light levels (up to factors of two) due to the differences in geometry and response of each LED. Our results are relatively insensitive to this effect because a) the pulse height data compare the response of the same LED as a function of either magnetic field or position, and b) only the time data compares information from different LEDs. The time data should be independent of the pulse height since we use CFDs.

The systematics of the time measurements can be tested with the information in data set 2. The information recorded 3 and 9 o'clock should be identical, but with different LED's. We show this information in Figure 10. Figure 10a plots our two data sets as well as a third measurement by the CEBAF Detector Group [4]. Differences of 300–400 ps are observed, but a similar overall trend is displayed by the three data sets. It is worth noting that time variations across the face of other PMTs tested was a couple of ns. The difference of our two measurements is plotted in Figure 10b as a function of the ratio of pulse heights. The data show a systematic shift of approximately 100 ps (2 counts) between the two data sets. An additional dependence on pulse height of the same order could be inferred. The systematic errors of comparing the response of the same LED as a function of magnetic field or location of the LED relative to the μ-metal shield should be significantly smaller.

2.2 Results

Figures 11 and 12 show the pulse height and time data superimposed on the same plot in order to summarize the results. From Figure 11, one sees that the photomultiplier in the 8"-long shield is affected by the field in a linear fashion even at very low fields. This indicates that the length of the shield is insuficient for our purpose. The shielding of the 11"-shield appears adequate up to approximately 20 G. Increasing the thickness of the shield by 50% should protect the photomultiplier tube up to 30 G.

Figure 12 shows the degradation of amplitude and timing of the photomultiplier tube as a function of distance between the PMT window and the edge of the μ-metal shield. The time measurements indicate that the protection is adequate even when the PMT is 4 cm from the edge of the μ-metal. However, the measurements in the 8" shield indicate that this distance is minimal. We therefore choose a safer distance of 2.5", closer to the rule of thumb which requires one diameter (3.3") of clearance.

3 Summary and Conclusions

The response of the XP4312B/D1 PMT enclosed in two magnetic shields was measured as a function of an external magnetic field perpendicular to the axis of the tube. Both shields were cylindrical tubes, 1-mm thick. The 11"-long shield adequately shielded the PMT from fields up to 20 G. The 8"-long shield was not long enough. Shown in Figure 13 is the XP4312B/D1 PMT along side a shield which is 9.5"-long, with measurements of the field strength. Note that the magnetic shield is longer than the measured countour lines by one inch at each end. These suggest that this length will be adequate for our purpose. In order to shield fields up to 30 G, we must increase the thickness to 1.5 mm.

ACKNOWLEDGEMENTS

We wish to thank Drew Weisenberger from the CEBAF Detector Group for organizing the apparatus used for the tests and very helpful discussions. We would also like to thank Tony Day for assistance in producing and debugging a PC board used to fire the LED's.

References

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

[2] Philips Components.

[3] Charles E. Gliniewicz, "Magnetic Fields Surrounding a Shield for the Photomultiplier Tubes in the CLAS TOF," CLAS-NOTE 93-008, August 13, 1993.

[4] E.S. Smith *et.al.*, "Tests of 3" Photomultiplier Tubes for the CLAS TOF," CLAS-NOTE 93-015, September 16, 1993.

List of Figures

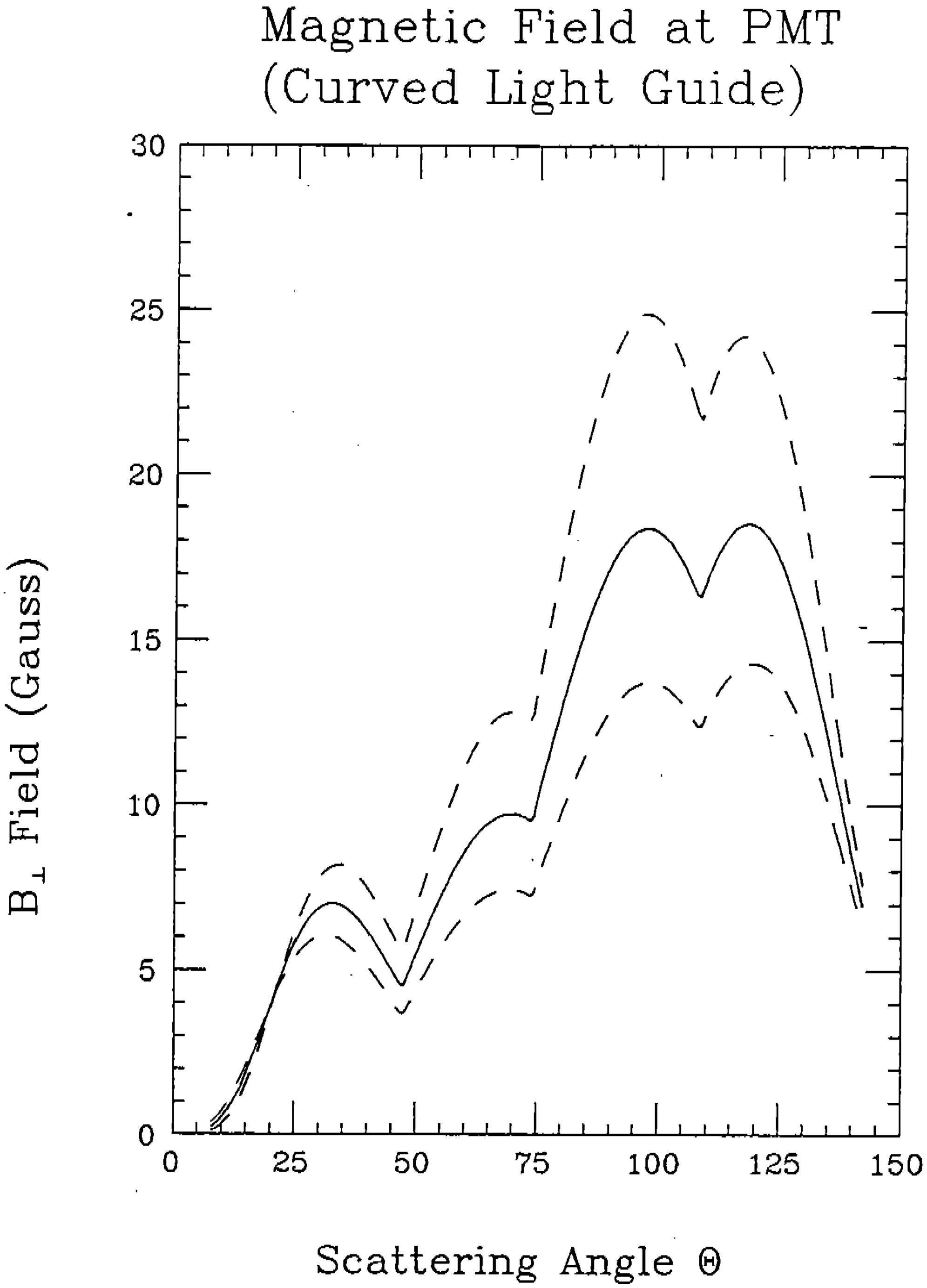


Figure 1: The field of the CLAS toroid is plotted at the position of the photomultiplier tubes of the TOF counters as a function of scattering angle. The structure of the field is caused by TOF planes which do not follow the approximately parabolic field lines. The solid line indicates present design for the location of the PMTs, the dashed curves show the variation of the field as the position is moved toward or away from the coil by 30 cm.

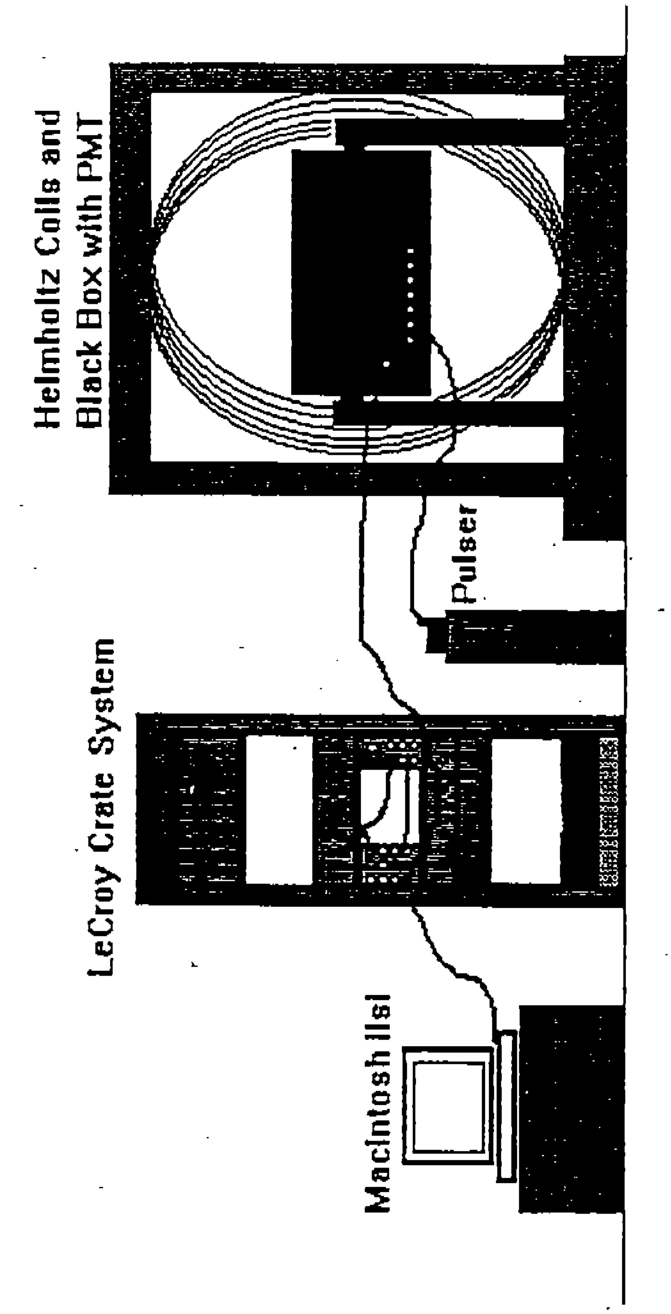


Figure 2: Setup of the dark box in the uniform, but variable, magnetic field produced by the Helmholtz coils.

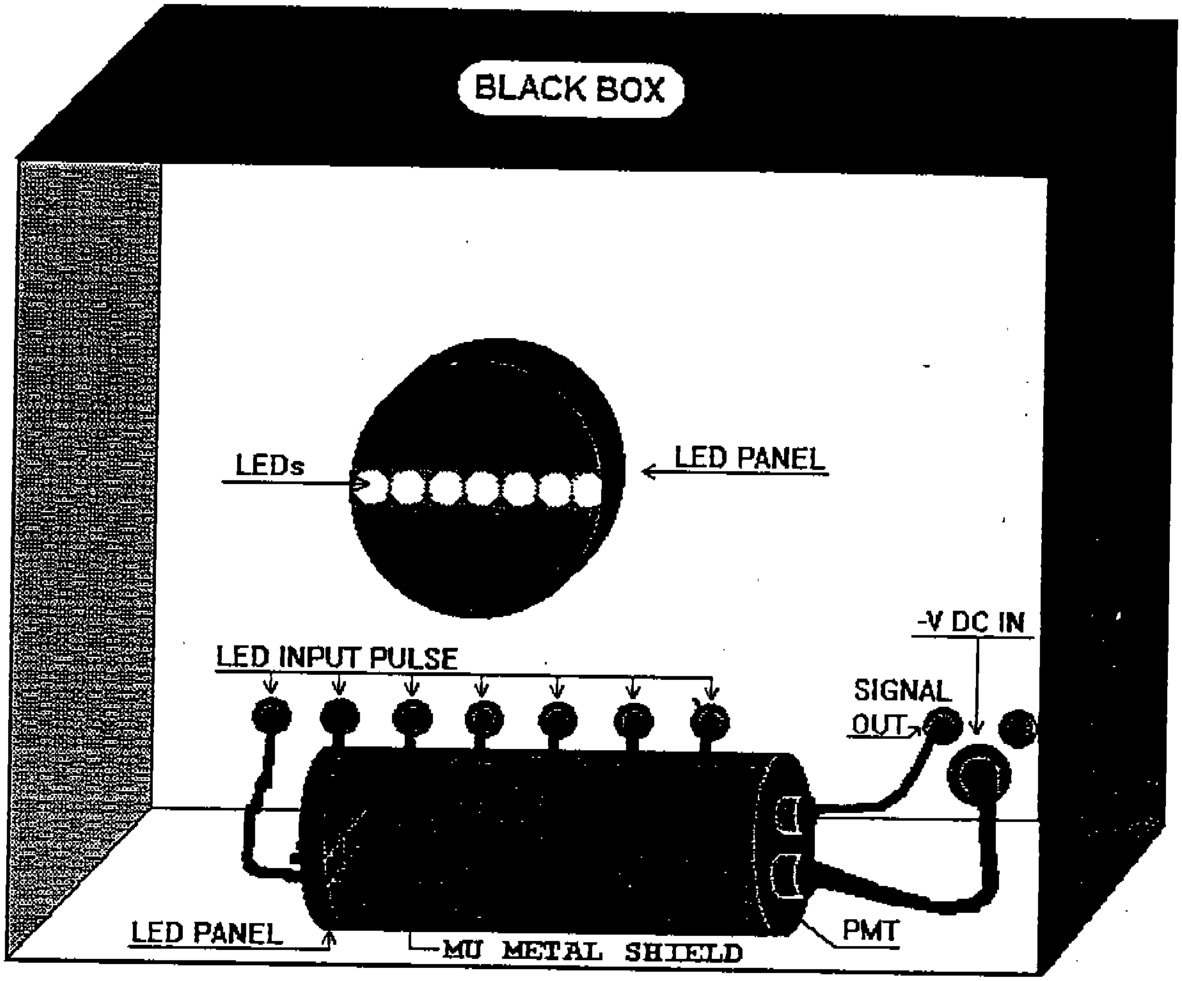


Figure 3: Setup of the photomultiplier tube in the dark box.

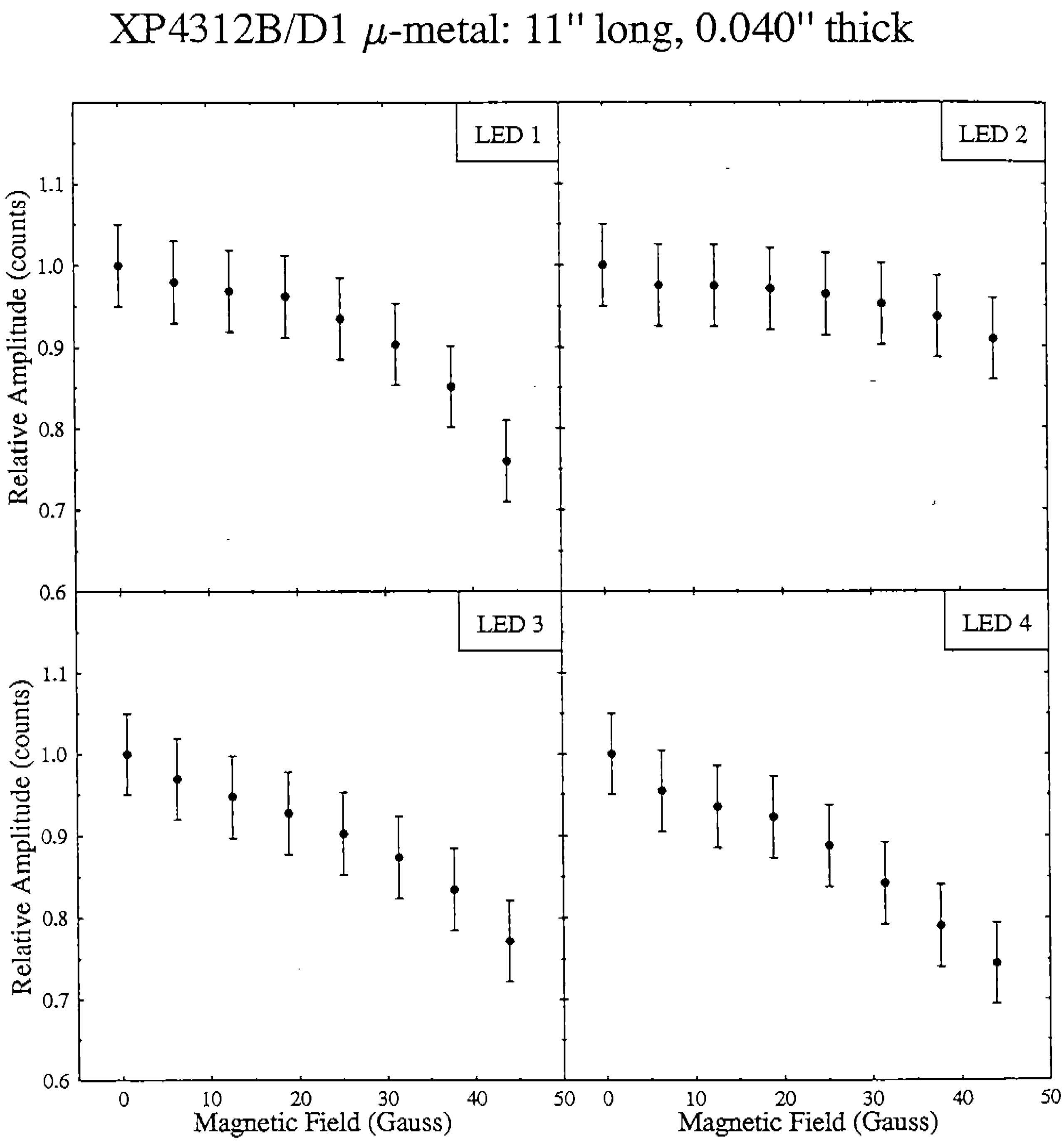
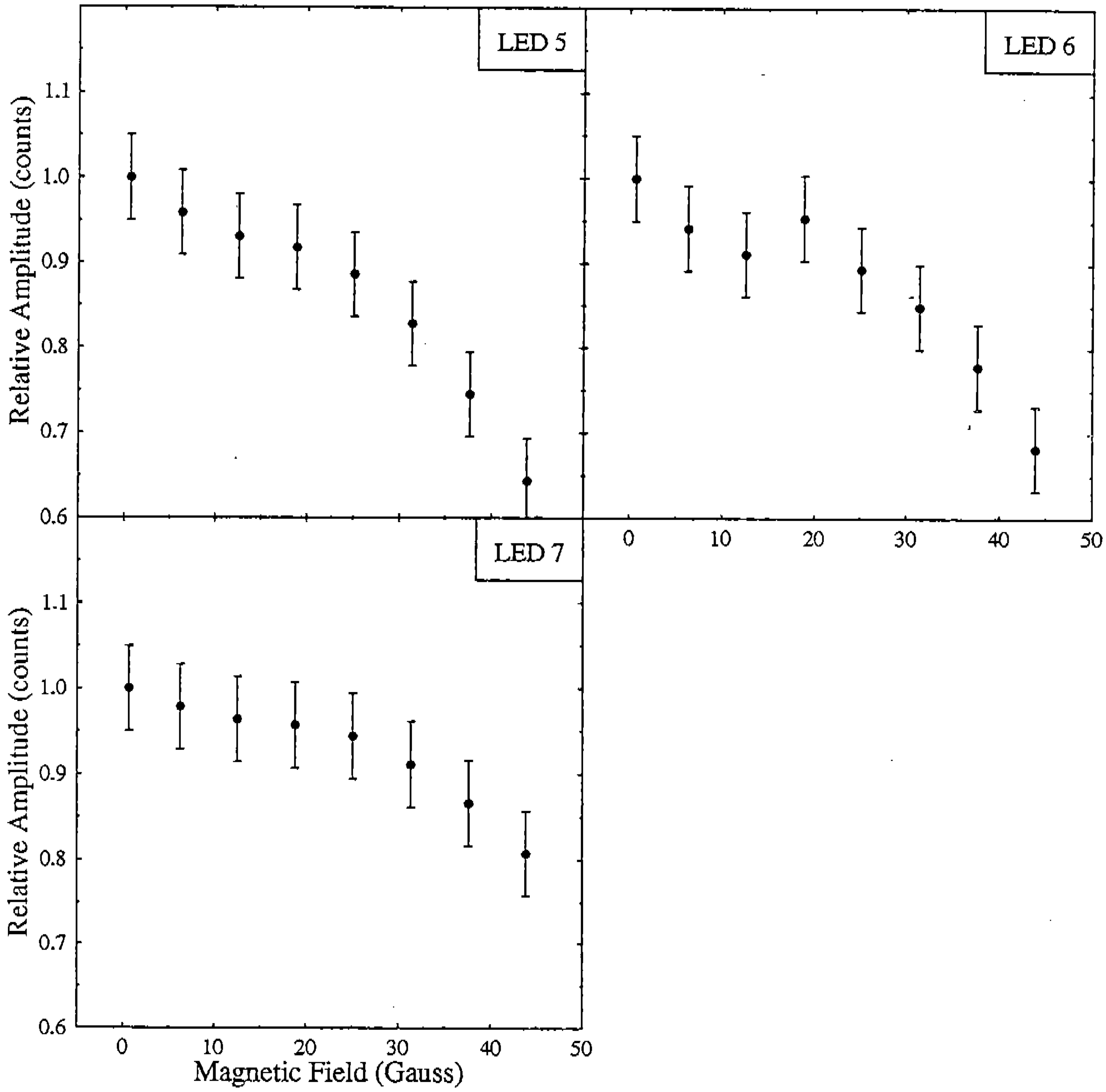


Figure 4: Pulse height variation as a function of magnetic field for 11" shield.

XP4312B/D1 μ-metal: 11" long, 0.040" thick



XP4312B/D1 μ-metal: 11" long, 0.040" thick

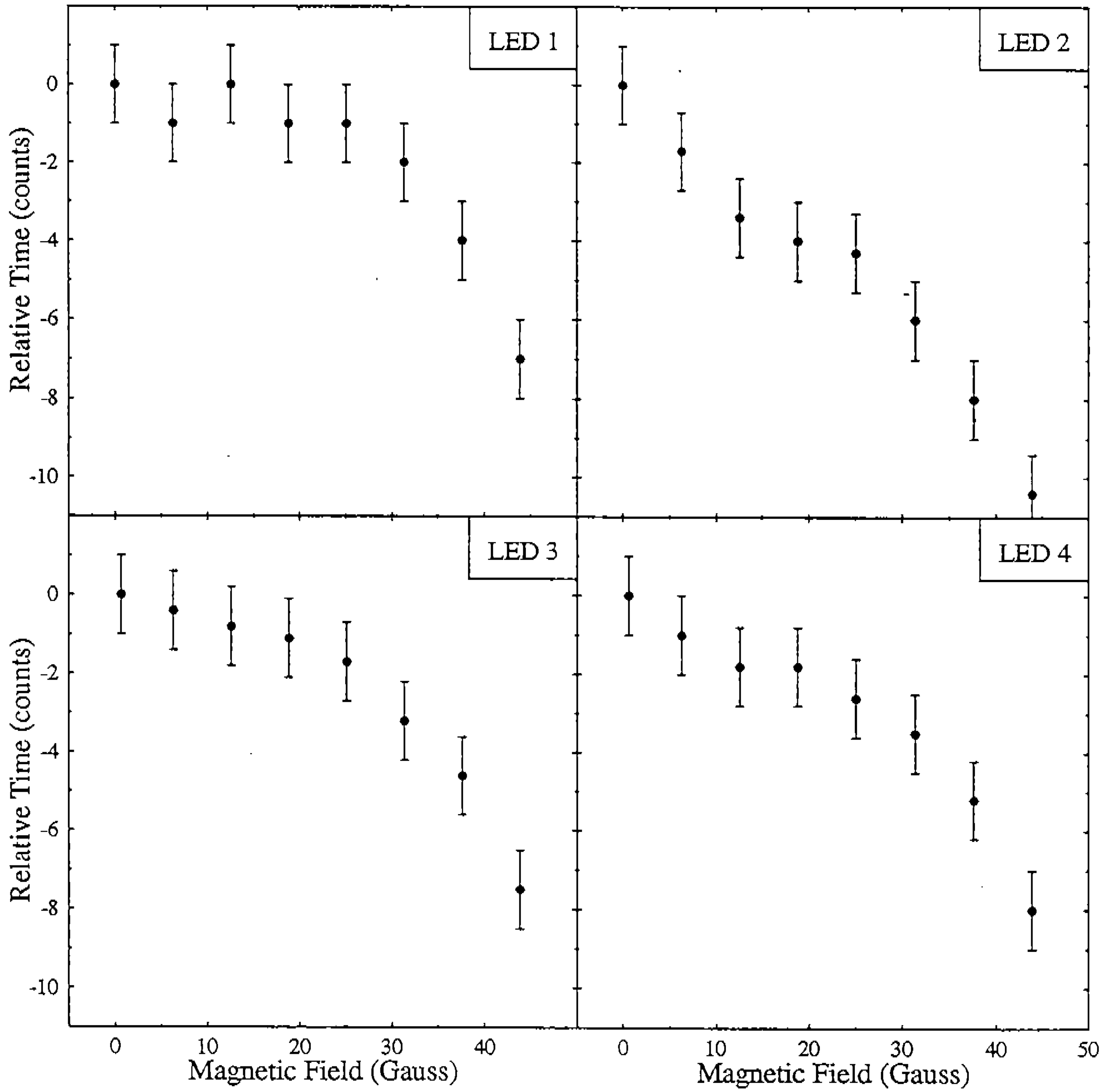
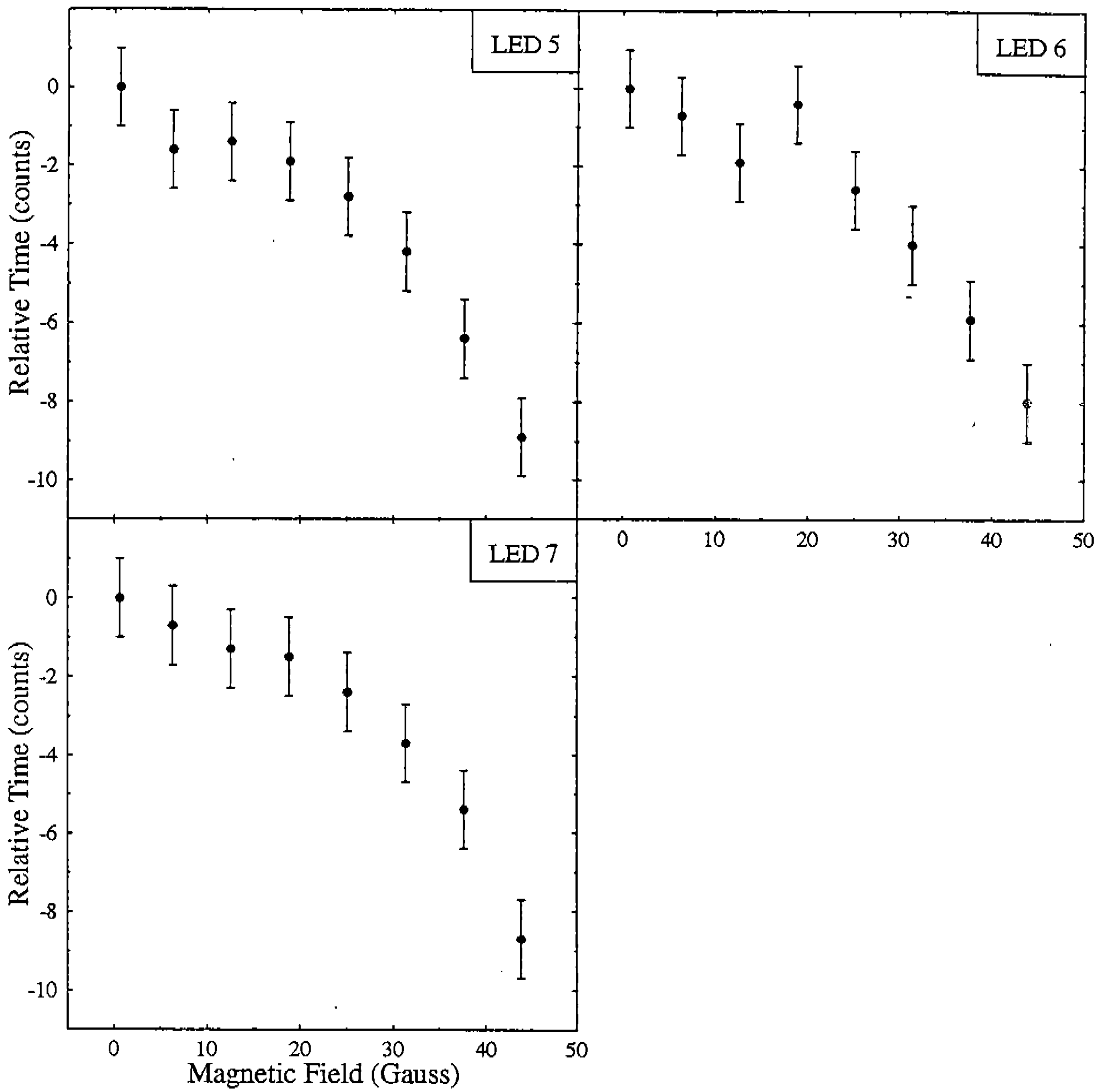


Figure 5: Time variation as a function of magnetic field for 11" shield.

XP4312B/D1 μ-metal: 11" long, 0.040" thick



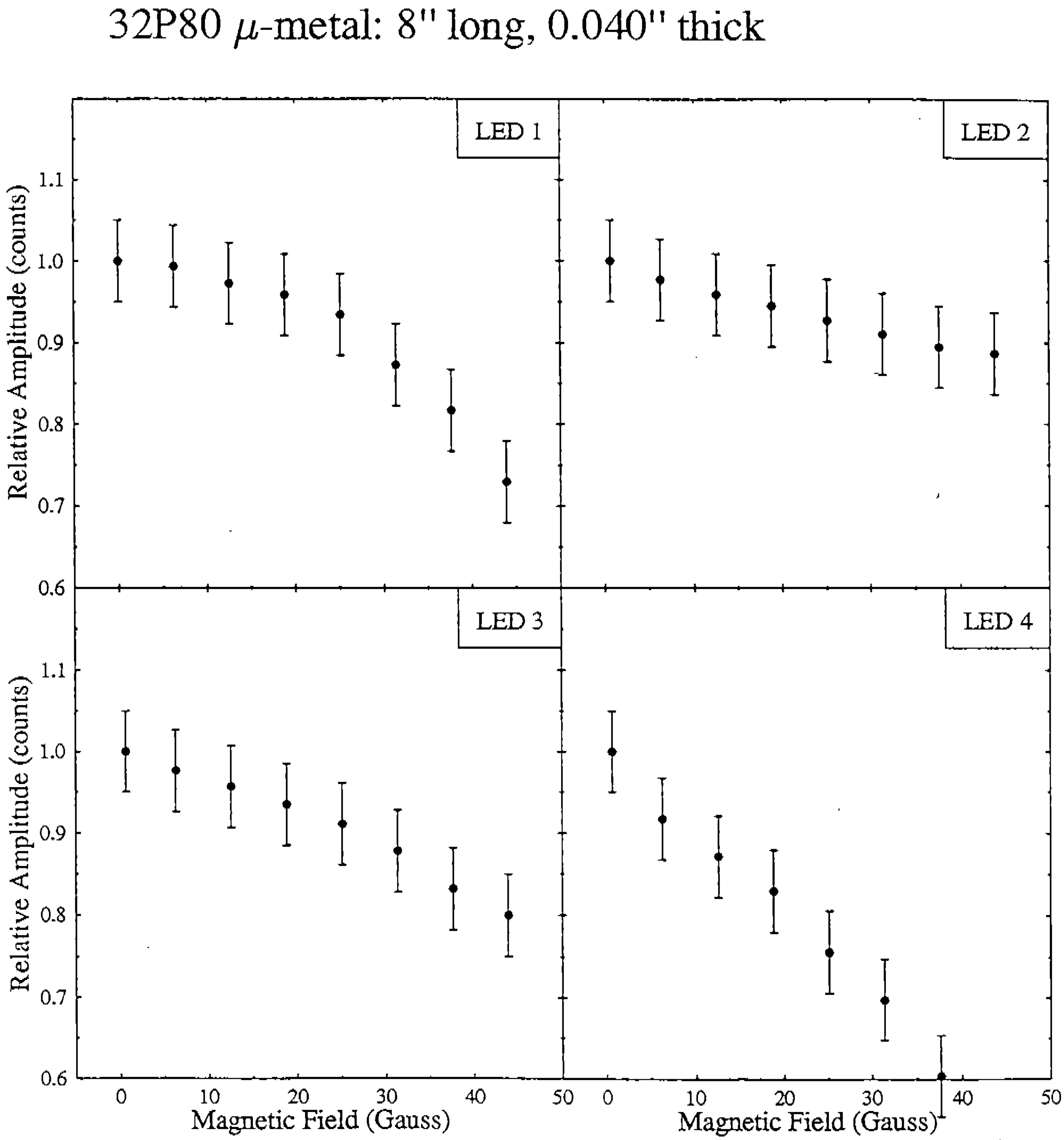
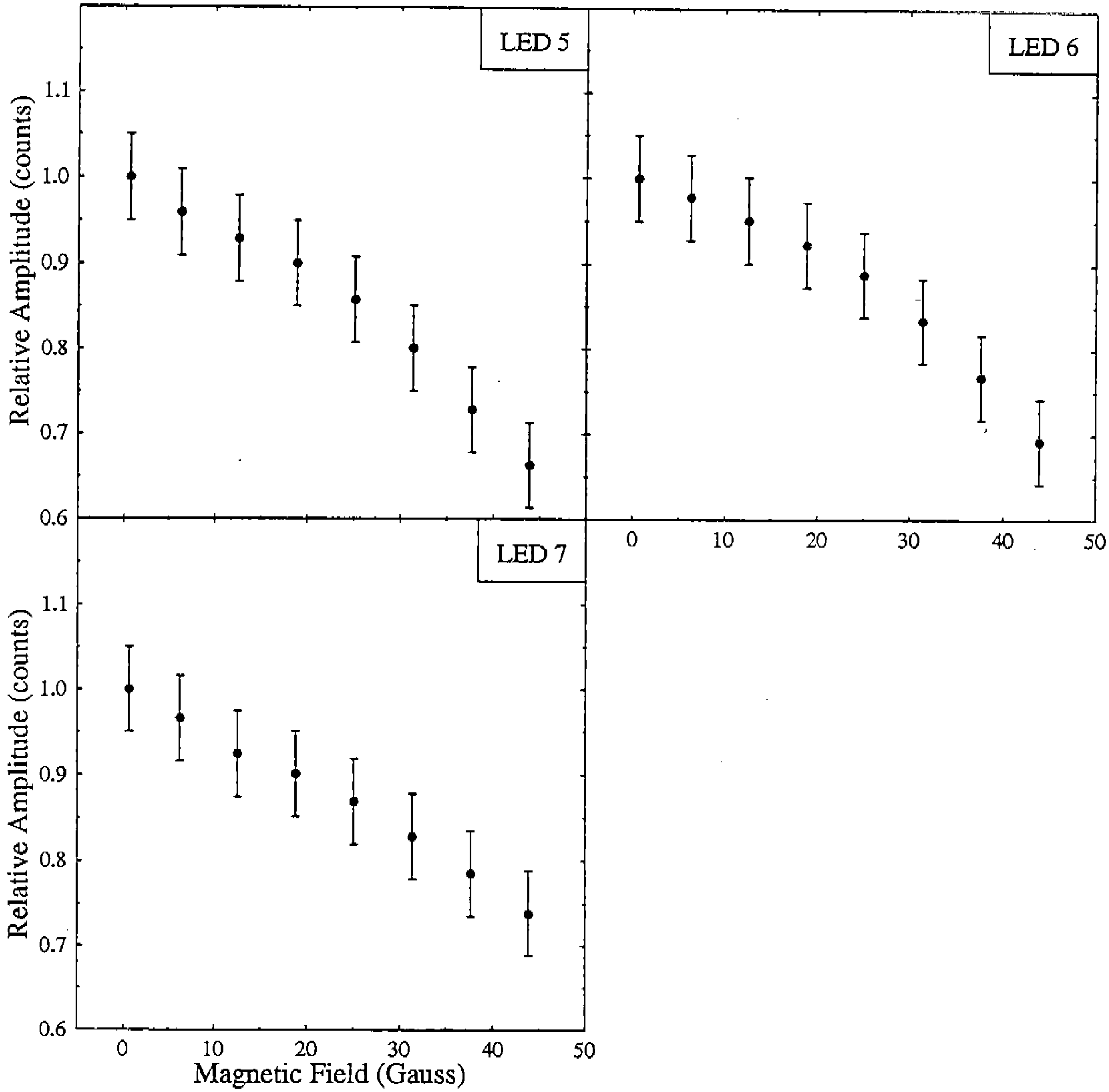


Figure 6: Pulse height variation as a function of magnetic field for 8" shield.

32P80 μ-metal: 8" long, 0.040" thick



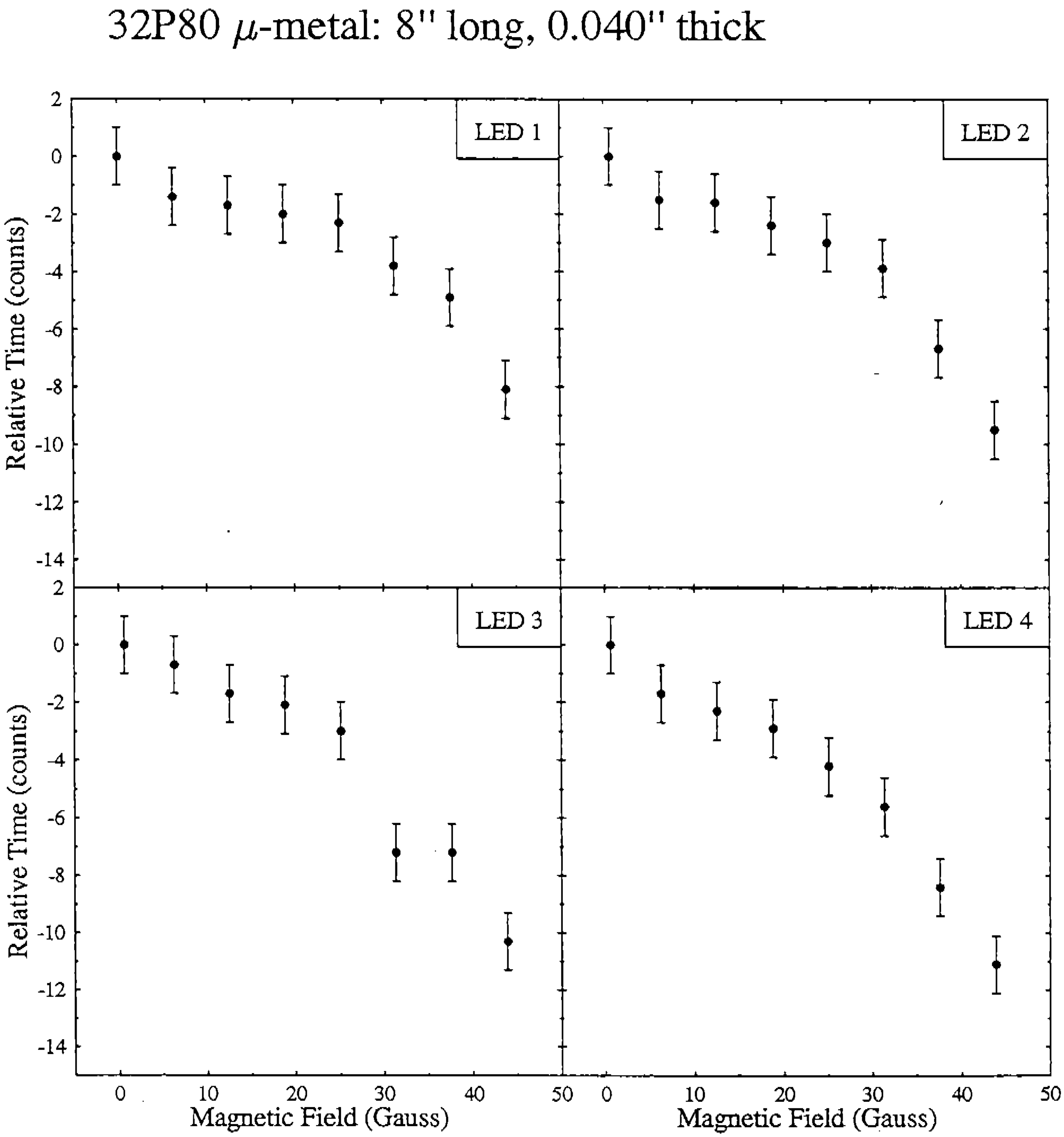
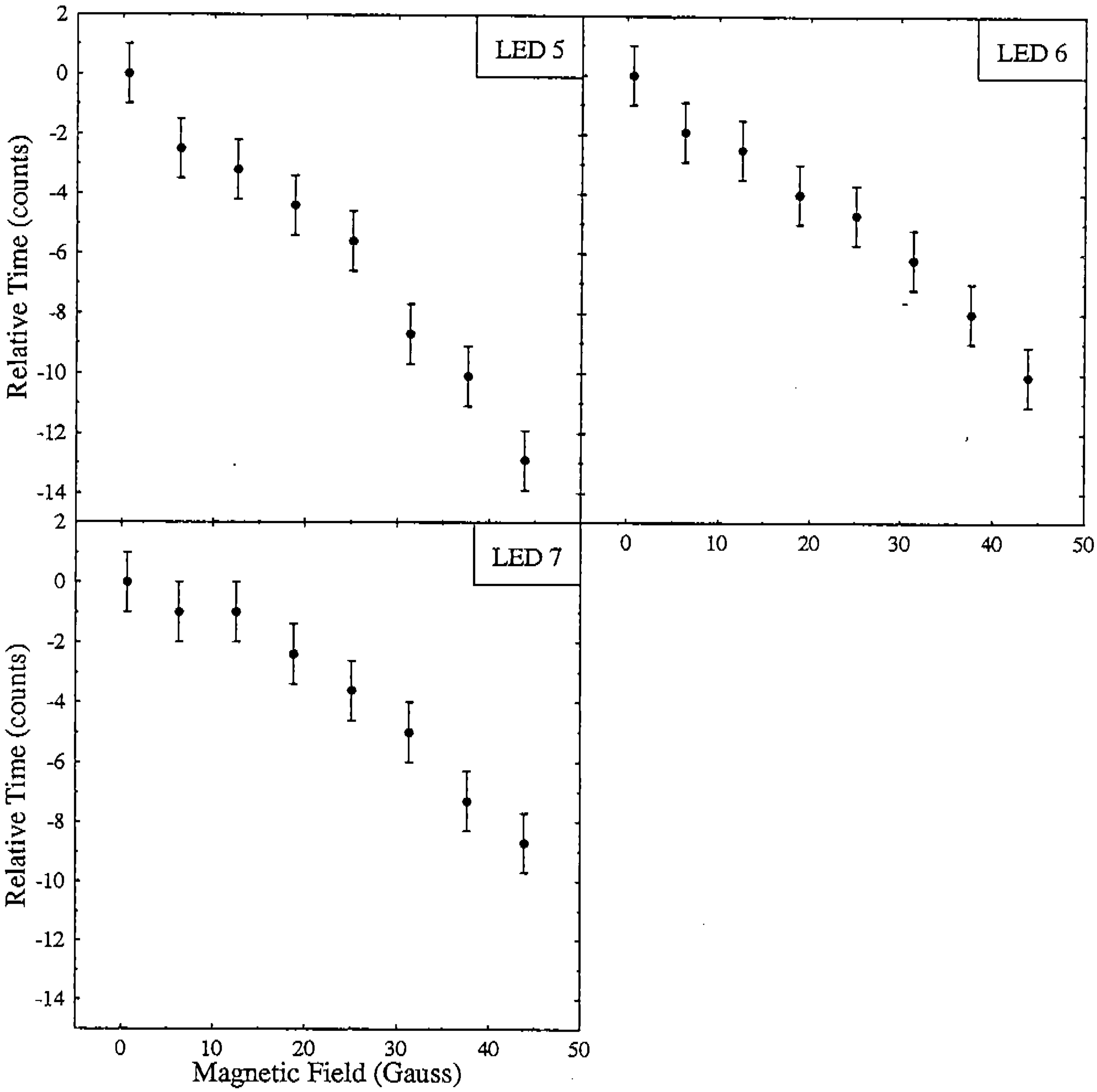


Figure 7: Time variation as a function of magnetic field for 8" shield.

32P80 μ-metal: 8" long, 0.040" thick



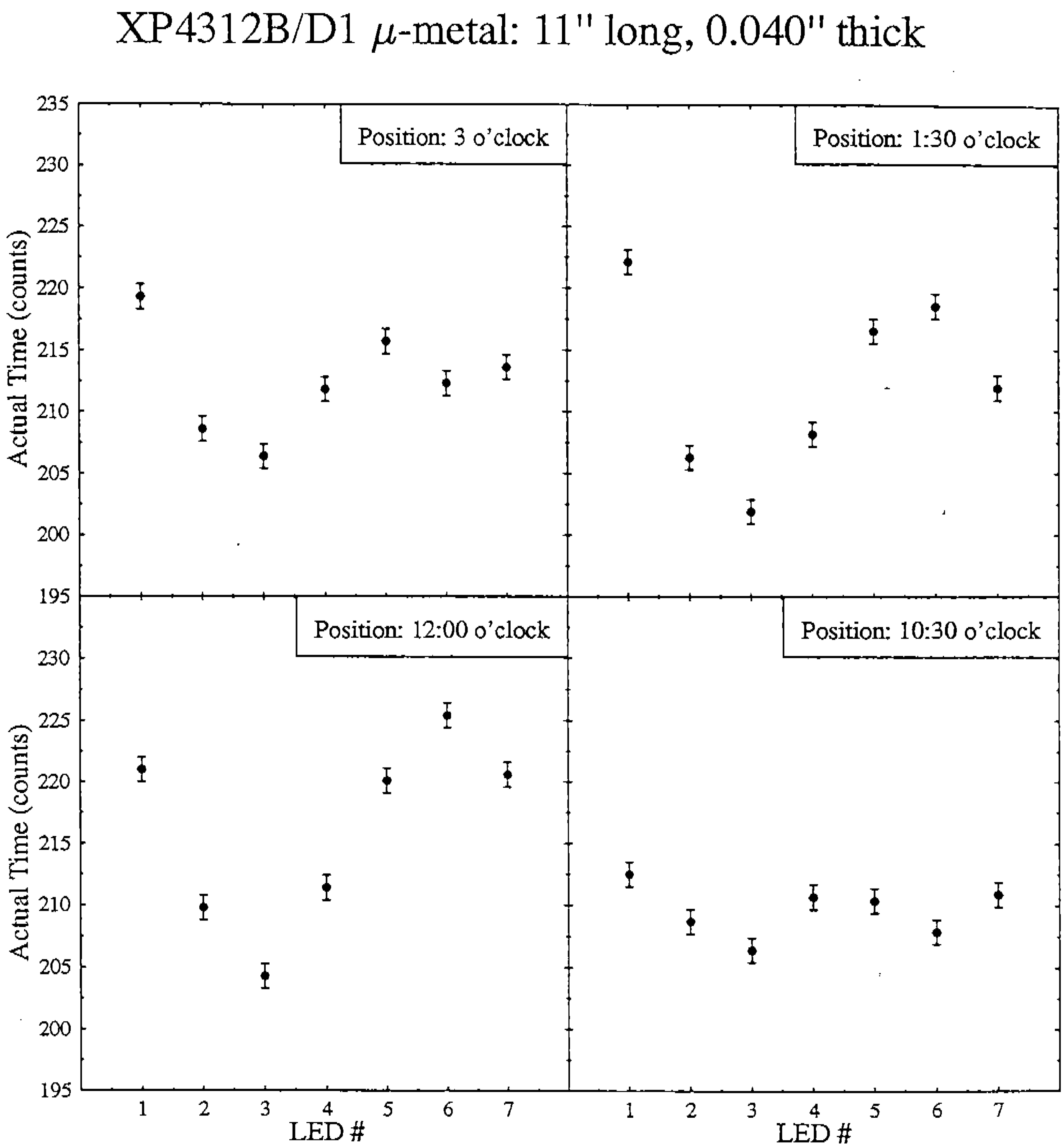


Figure 8: Time variation across various diameters of the photomultiplier tube.

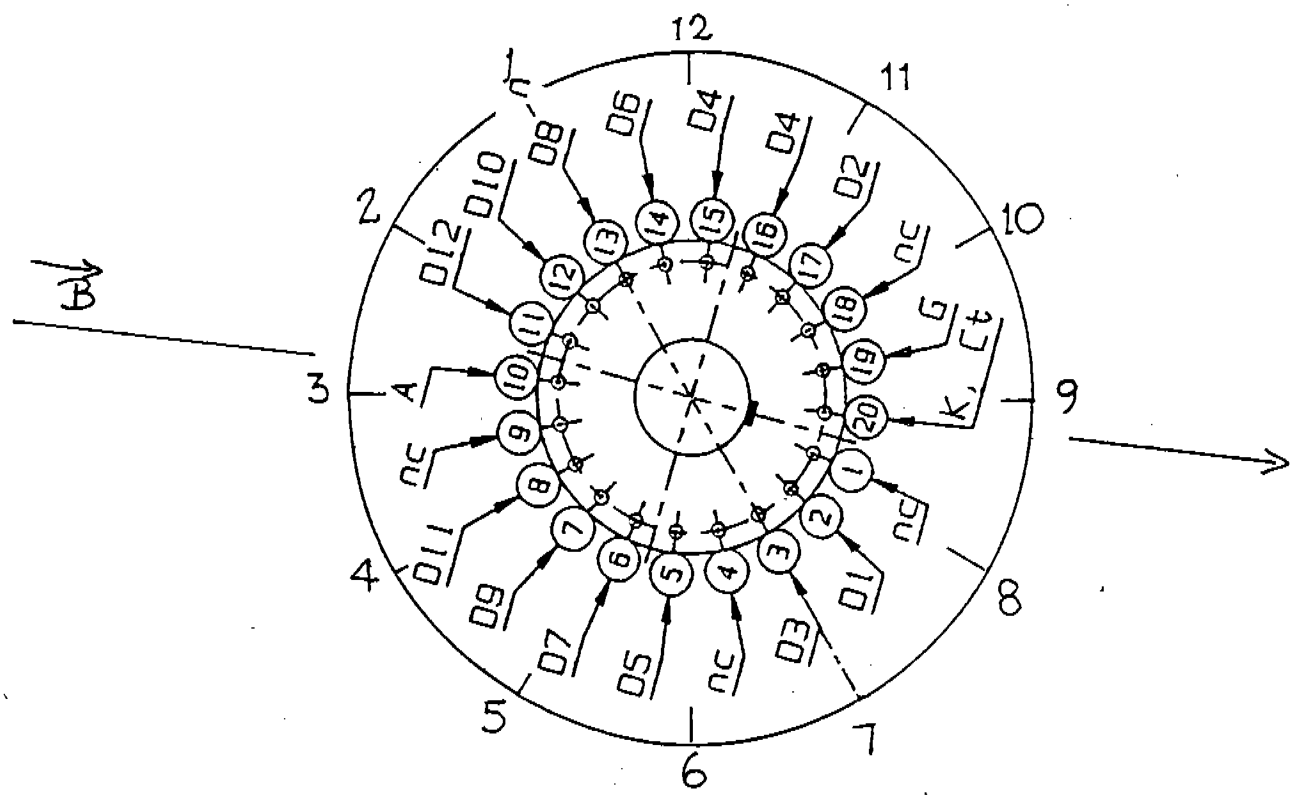
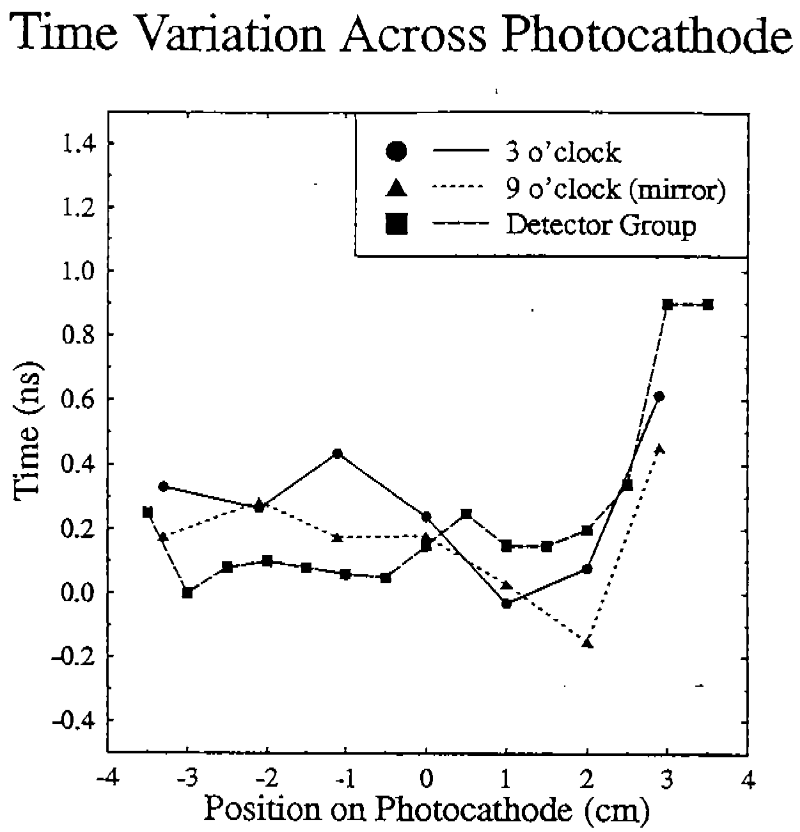


Figure 9: Orientation of the field relative to the photomultiplier socket.



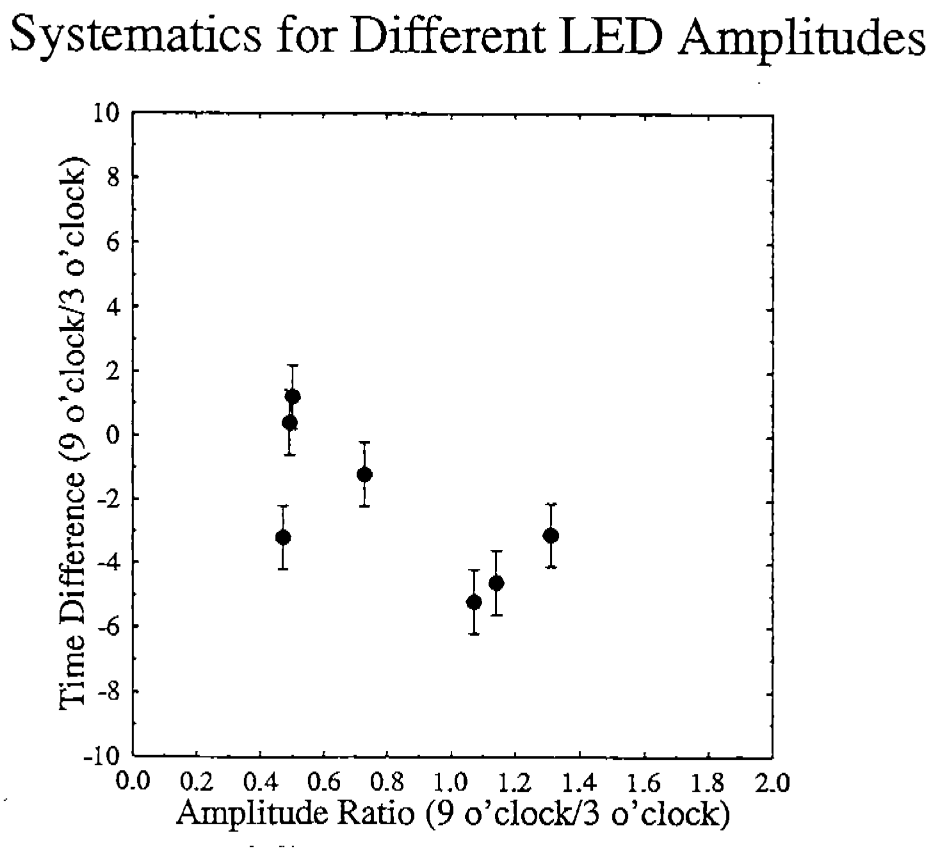


Figure 10: Systematic time shifts due to LED pulse heights. a) comparison of three different measurements across one PMT diameter. b) Difference of the time measured as a function of the ratio of the pulse heights of two different LEDs.

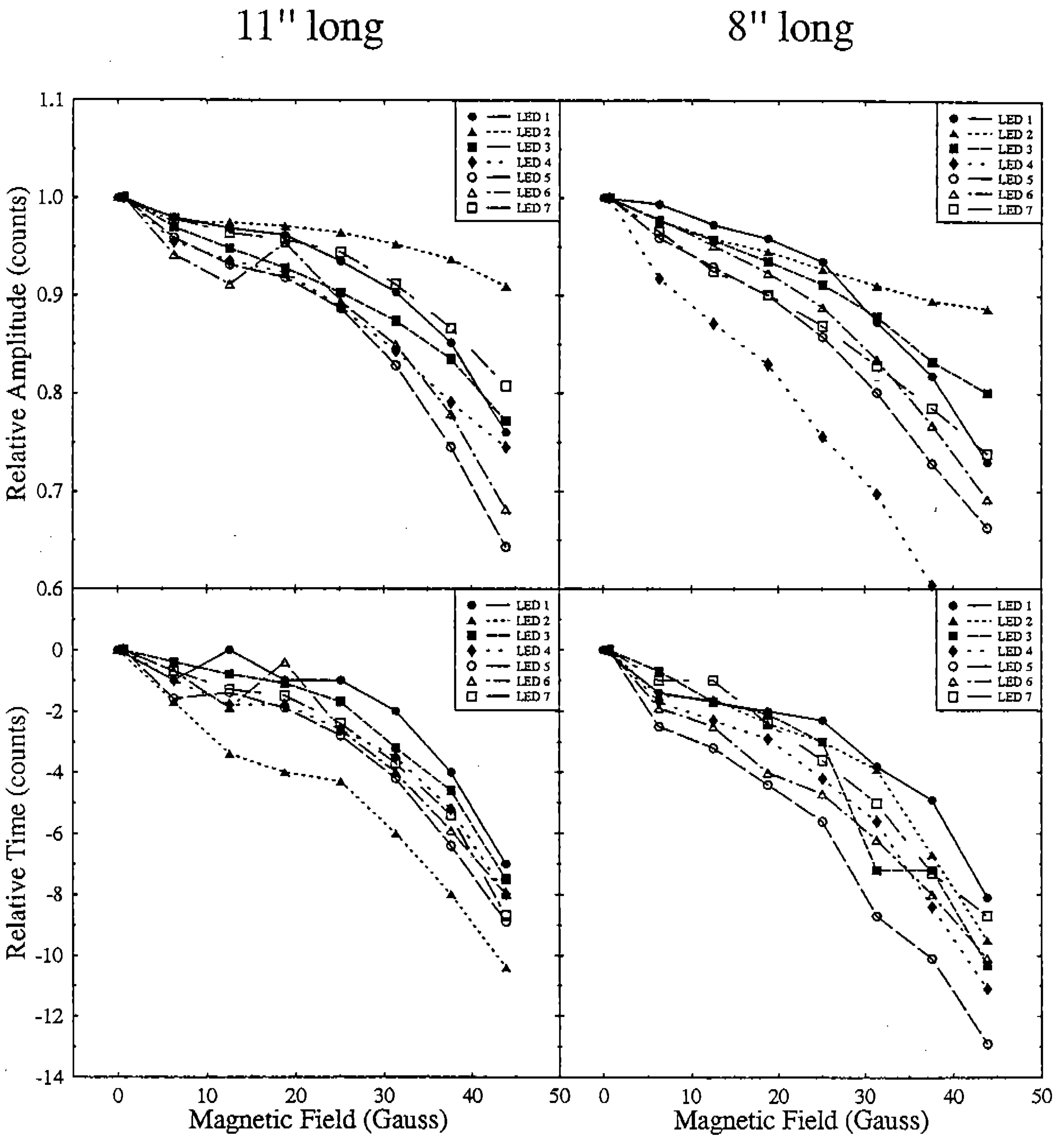


Figure 11: Summary of pulse height and time measurements for the 11" and 8" shields as a function of magnetic field.

Cathode to μ-metal

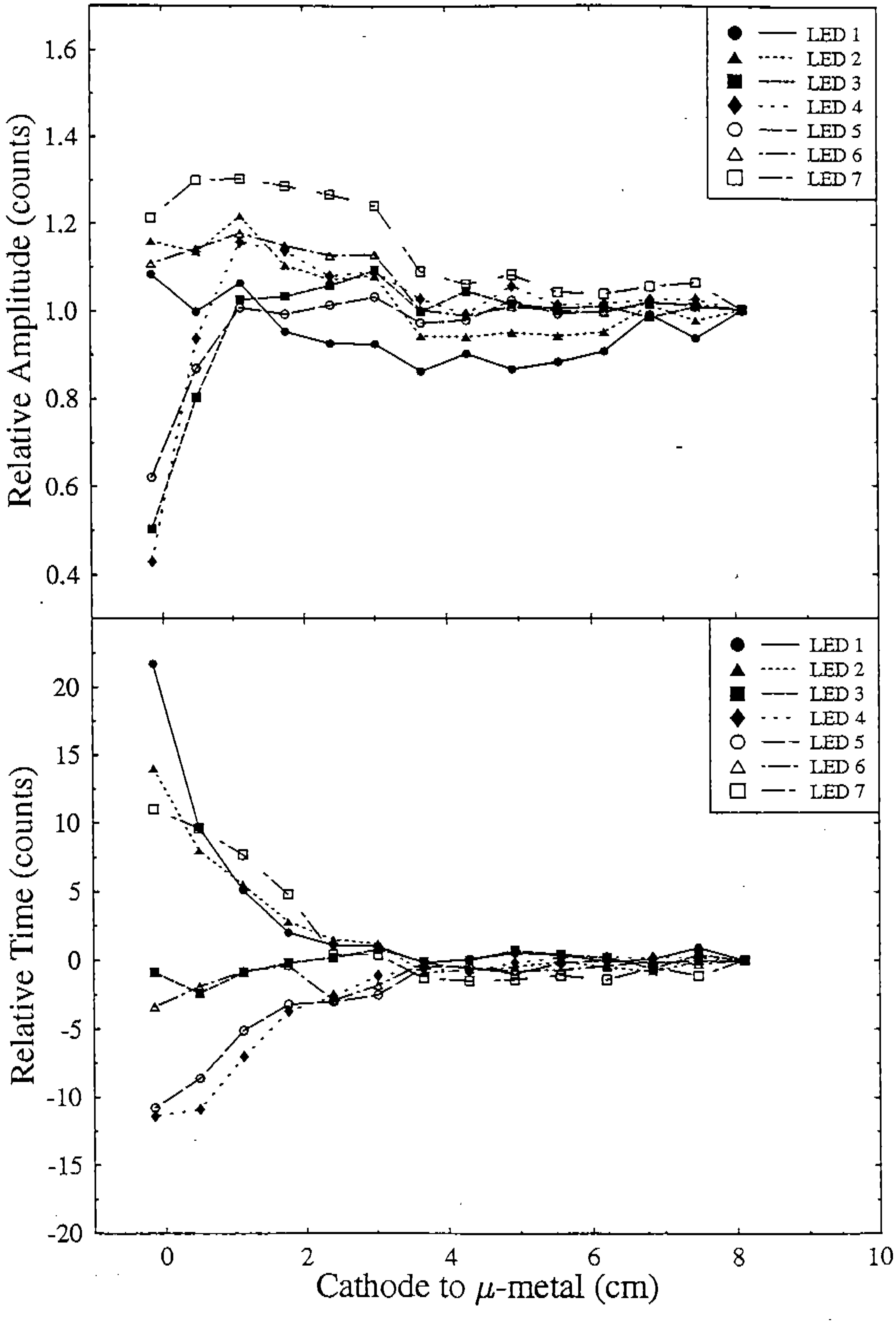


Figure 12: Summary of the pulse height and time measurements as a function of the relative position between the photomultiplier tube window and the edge of the μ-metal shield.

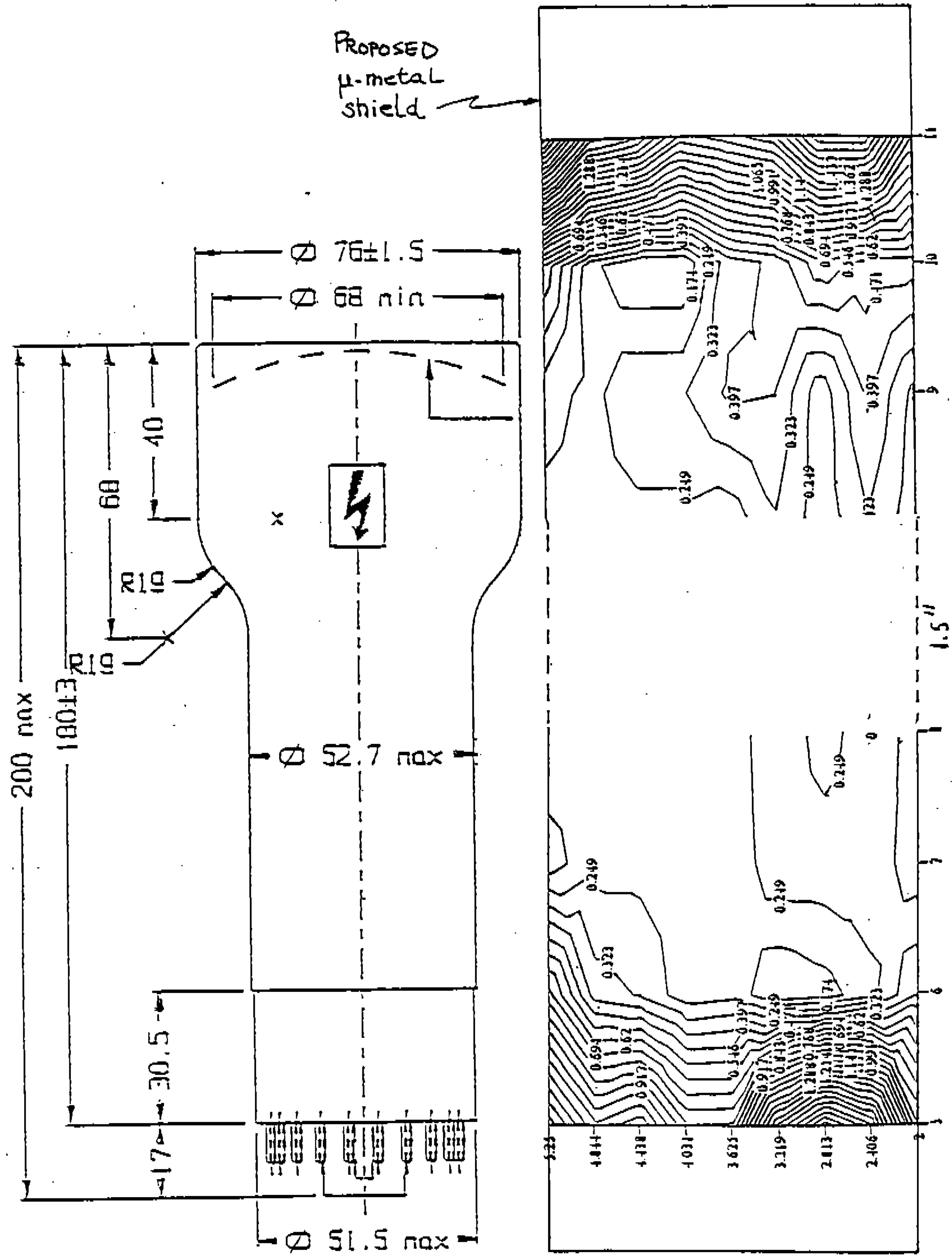


Figure 13: The XP4312B photomultiplier is compared to the proposed μ-metal shield. The contours of residual field inside the shield were measured for an external field of 30 G, an 8" shield of 0.040" thick [3]. We propose to increase the length of the shield to 9.5" and the thickness to 0.060".