TIME CALIBRATION: STABILITY STUDIES

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1 Introduction.

Three laser calibration runs, two of them partial, allow us to compare time calibration results to study slewing shape stability, pedestal drifts, and other timing changes, across time intervals of 1 month or 5 months. We list the times and conditions below, then will refer to them by the month of the run for brevity.

OCTOBER Data taken October 27-29, 1999. Complete Slewing Curves and Time Pedestals, and partial PE calibration. All 30 laserballs; 708(702) PMT's calibrated for low(high) TOT respectively. For laserballs 1-10 the laser was running at lower light levels and large amplitude variations, allowing Slewing and Tped calibration, but not PE calibration.

NOVEMBER Data taken November 18-20, 1999. Complete Slewing Curves for PMT's served by Laserball 1-10 (except ball 3). Light levels high and stable, allowing completion of PE calibration, and the stretching of the OCTOBER slewing curves to higher TOT for this subset of the PMT's, and time pedestals. Laserball 3 had no light output.

MARCH Data taken March 9, 2000. Data at only two light levels for 643 PMT's. Laser was not very stable. Allows the calculation of fresh time pedestals. Laserball 3 and 22 had no light output.

In all figures throughout this memo the units of time are TDC counts. One TDC count is 0.5ns.

2 Reproducibility of Slewing Shapes.

For the 236 PMT common to the OCT and NOV data sets we compare HiToT slewing shapes in the region of TOT that overlaps. Fig. 1 shows examples of the comparison for

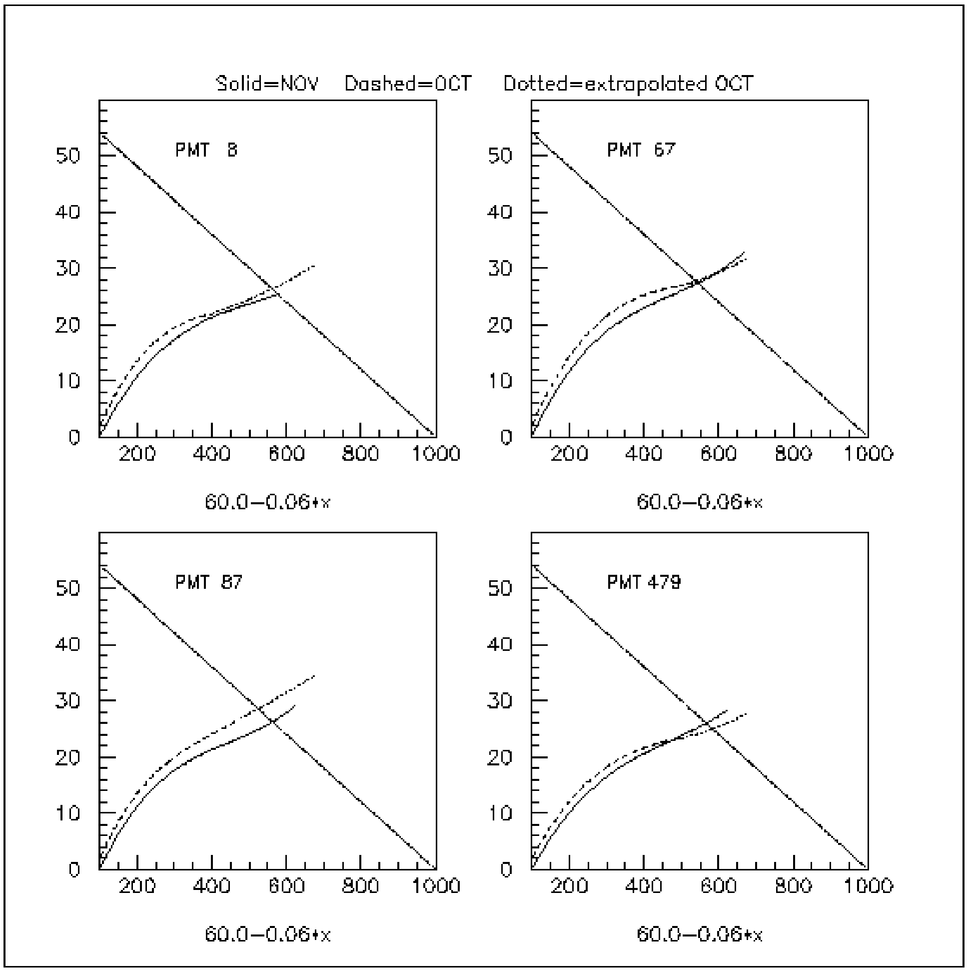

Figure 1: Four Slewing Shapes. For visibility, curves are plotted with an imposed offset of 2 counts at left edge. Diagonal is drawn to set a common scale.

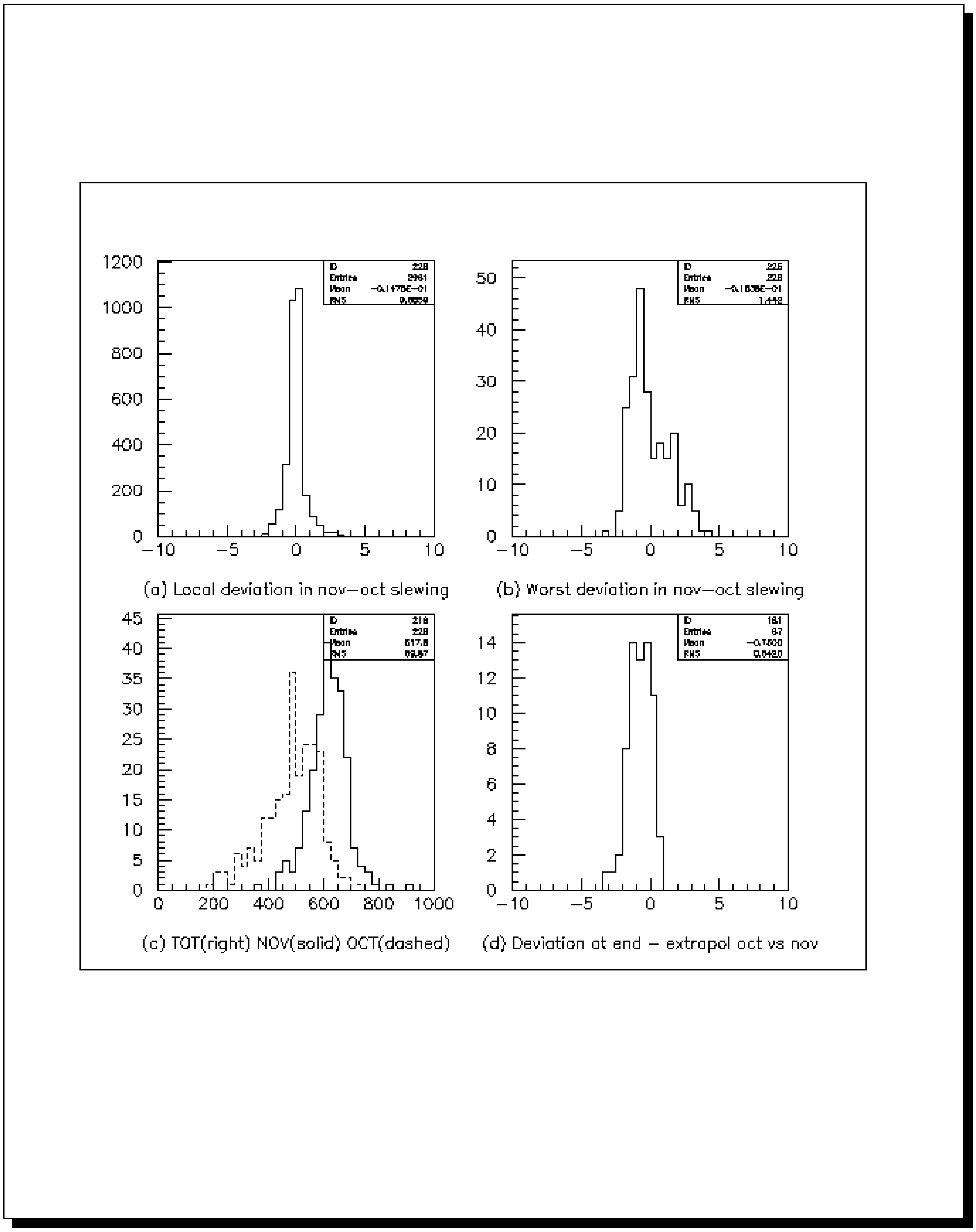

Figure 2: Shape Comparison Distributions.

4 PMT's. Figs. 2 (a,b) show histograms of the local deviations and the worst deviations between slewing shapes (each sampled at 25count TOT intervals). The RMS of the local deviations is 0.7 counts. The worst deviation for each PMT ranges up to 4 counts with an RMS of 1.4 counts. We conclude that the slewing shapes are quite stable.

For the PMT's serviced by laserballs 1-10 the gain in measured slewing range from OCT to NOV is quite significant, as seen on Fig. 2(c) by comparing the right edge of the fit for NOV (solid) and OCT (dashed). This extended slewing range also allows us to do a direct test of the extrapolation, by comparing extrapolated OCT to measured NOV curves. Fig. 2(d) is a distribution of the deviations at the end of the NOV fit range, for extrapolation distances of 100 counts or more. The RMS deviation from zero, 1.1 counts, is in good agreement with the error estimate of the *random function method* in our memo describing the extrapolation[1].

Given the stability of the slewing shapes, we produce improved slewing shape calibration constants by mixing the OCT and NOV data, using the longer-TOT-range NOV data for 236 PMT's and keeping the OCT data for the other PMT's. We will call this new mixed slewing shape set LONG and use it for all the analysis of time pedestals below[2]. In terms of the polynomial fit, the slewing shape is given by coefficients c1,c2,c3... of the nonzero powers of the polynomial. The coefficient c0, fitted with the other coefficients held constant, gives the time pedestal.

3 Speed of Light and Fiber Delays.

Once we have defined the common set of slewing shapes LONG, we apply it to any full or partial data by looking at the laser calibration times after the slewing shape correction to obtain time pedestals. As step one we refit the speed of light in water and relative laserball fiber lengths using the MAR data only, to compare to the original OCT data values.

The fitted speeds of light, tabulated below, agree well with each other and also with Milagrito[3].

- v=11.04cm/count for MARCH
- v=11.02cm/count for OCTOBER
- v=11.06cm/count for MILAGRITO

Relative laserball fiber-optics delays are obtained by comparing the time-pedestals of a subset of PMT's using different laser-balls. Fig. 3 is a scatterplot of MAR vs OCT measured

[1]Milagro Memo: *Slewing Extrapolation.*, L. Fleysher, R. Fleysher, A. Mincer, and P. Nemethy, 4-20-00.
[2]Calibration files implementing this are ready for installation in next version of reconstruction.
[3]Milagro Memo: *Timing Pedestals II*, L. Fleysher, R. Fleysher, and P. Nemethy, 11-1-97.

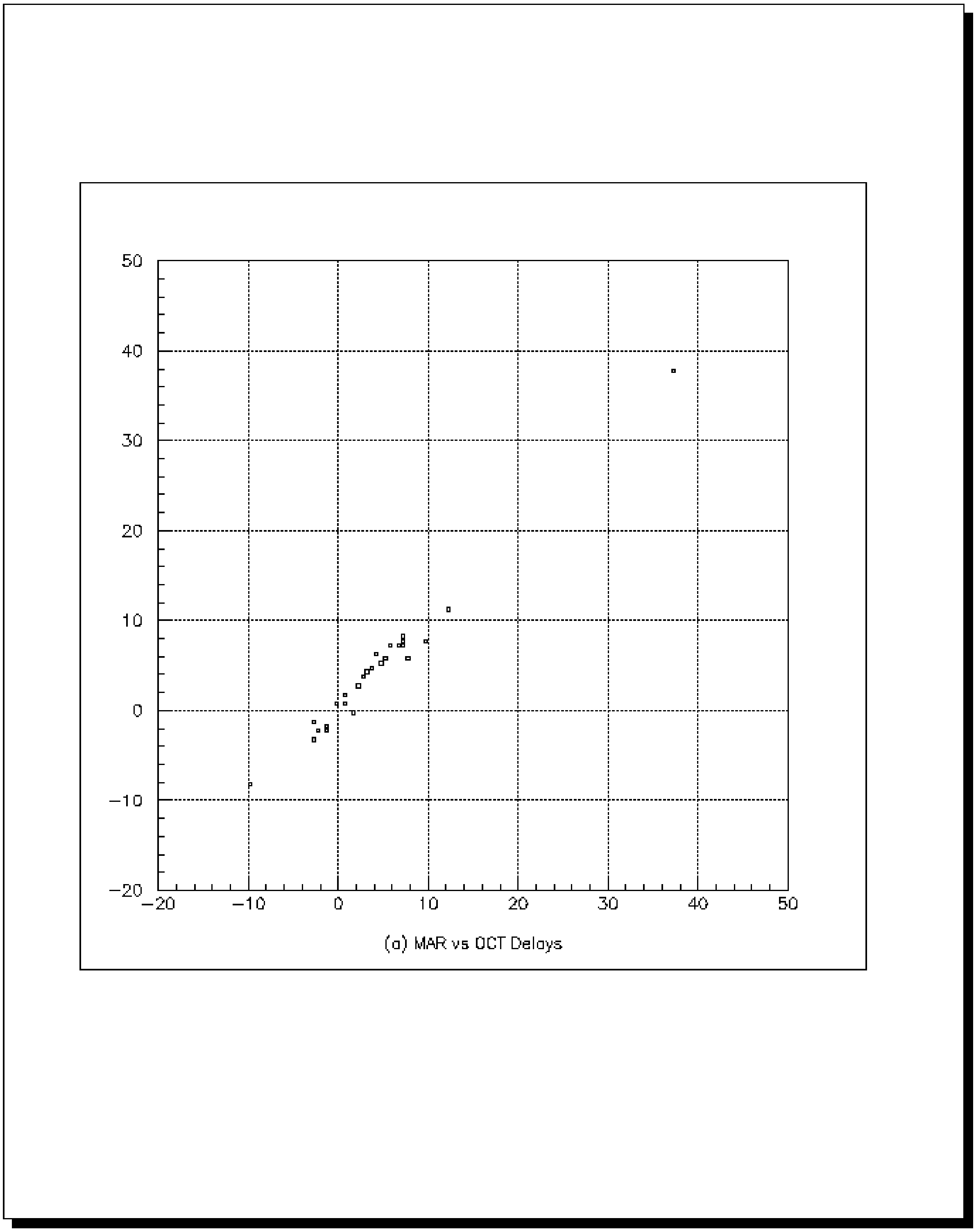

Figure 3: Laserball Fiber Delay Correlation.

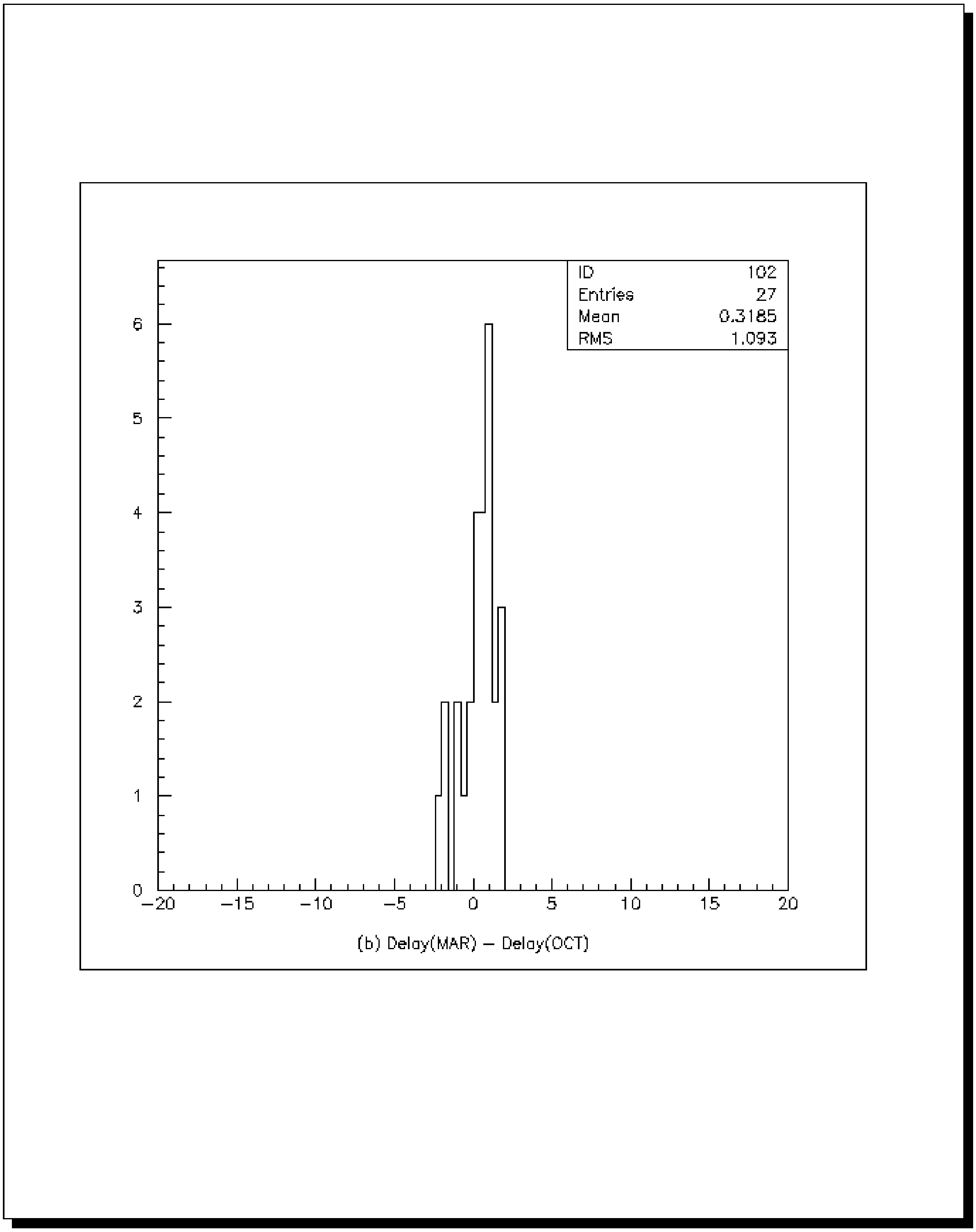

Figure 4: Laserball Fiber Delay Differences.

relative fiber delays (with respect to ball 30). The relative fiber delays span a range of about 45 counts; we see that taking them into account when evaluating time pedestals is quite important. The scatterplot shows excellent correlation between the MAR and OCT values. We make this quantitative in Fig. 4, the distribution of march to october delay differences. The RMS difference is 1.1counts and the worst case is 2.3counts. Fiber delays are stable.

4 Time Pedestal Drift Studies.

For a given set of data, time pedestals are the measured coefficients c0 corrected for the fiber-delay differences and for the time-of-propagation in water between laserball and PMT, using survey coordinates and the measured speed of light in water.

For reconstructing shower directions from data in a given layer, only drifts in the relative time pedestals in that layer matter. The common trigger time for the layer does not affect the fit. Our three calibrations allow us to make two independent pedestal drift comparisons; we choose these to be NOV - OCT and MAR - OCT.

Figs. 5(a) and 5(b) give NOV-OCT and MAR-OCT time-pedestal differences respectively, when PMT's from the Muon(MU) layer Air-shower(AS) layer are all included. While Fig. 5(a) was no surprise, Fig.5(b) is unexpected, showing twin peaks, indicating two components in the distribution. The two peaks turn out to correlate perfectly with layer, as seen in Figs. 6(a) and 6(b) MAR-OCT differences for AS and MU separately. We tabulate the common, average trigger shifts below.

- Common Trigger Shift=-3.7 counts for NOV - OCT
- Common Trigger Shift=-26. counts for MAR - OCT (AS)
- Common Trigger Shift=-37. counts for MAR - OCT (MU)

Since we are completely blind to layer in the calibration procedure, which treats all PMT's identically, we believe this difference is real, not generated in the calibration analysis. None of us, including our electronics experts, have been able to come up with a layer-dependent electronics change to account for the 11count shift between the MU and AS layers, nor explain the large value of both shifts.

The only known difference between layers is the length of the coax, which is about 100ft shorter for the MU than for the AS PMT's. However, a possible explanation, namely a small MAR OCT temperature change giving a different cable propagation time for MU and AS was eliminated with a direct measurement by Dave Williams of the temperature dependence of the coax propagation time, $-3 \cdot 10^{-4} \frac{1}{^{\circ}C}$, too small by more than an order of magnitude.

Within a layer the relative time-pedestal drifts of Figs. 6(a) and (b) are small, ranging to less than 4 counts, with RMS drifts tabulated below.

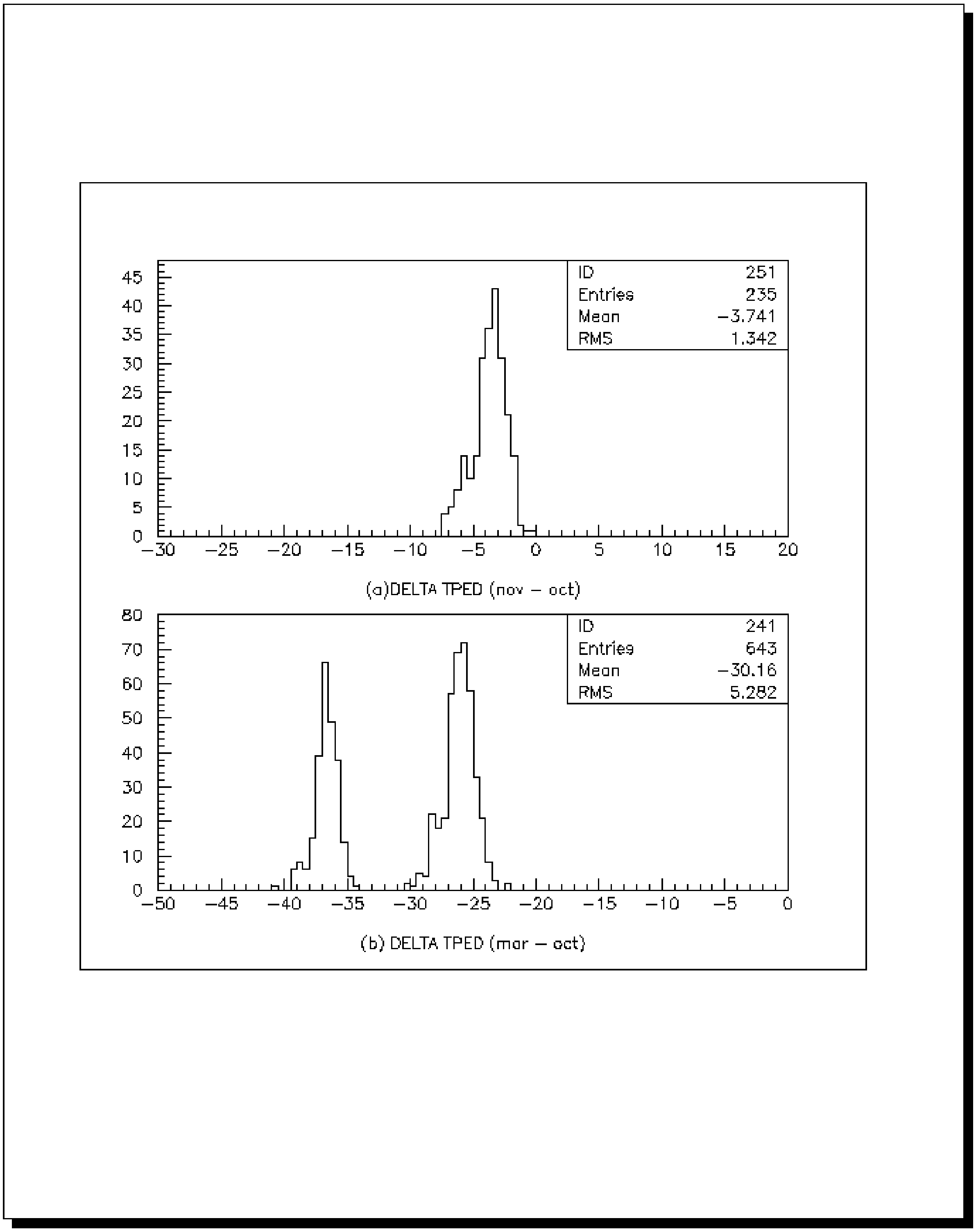

Figure 5: Time Pedestal Drifts; NOV and MAR vs OCT .

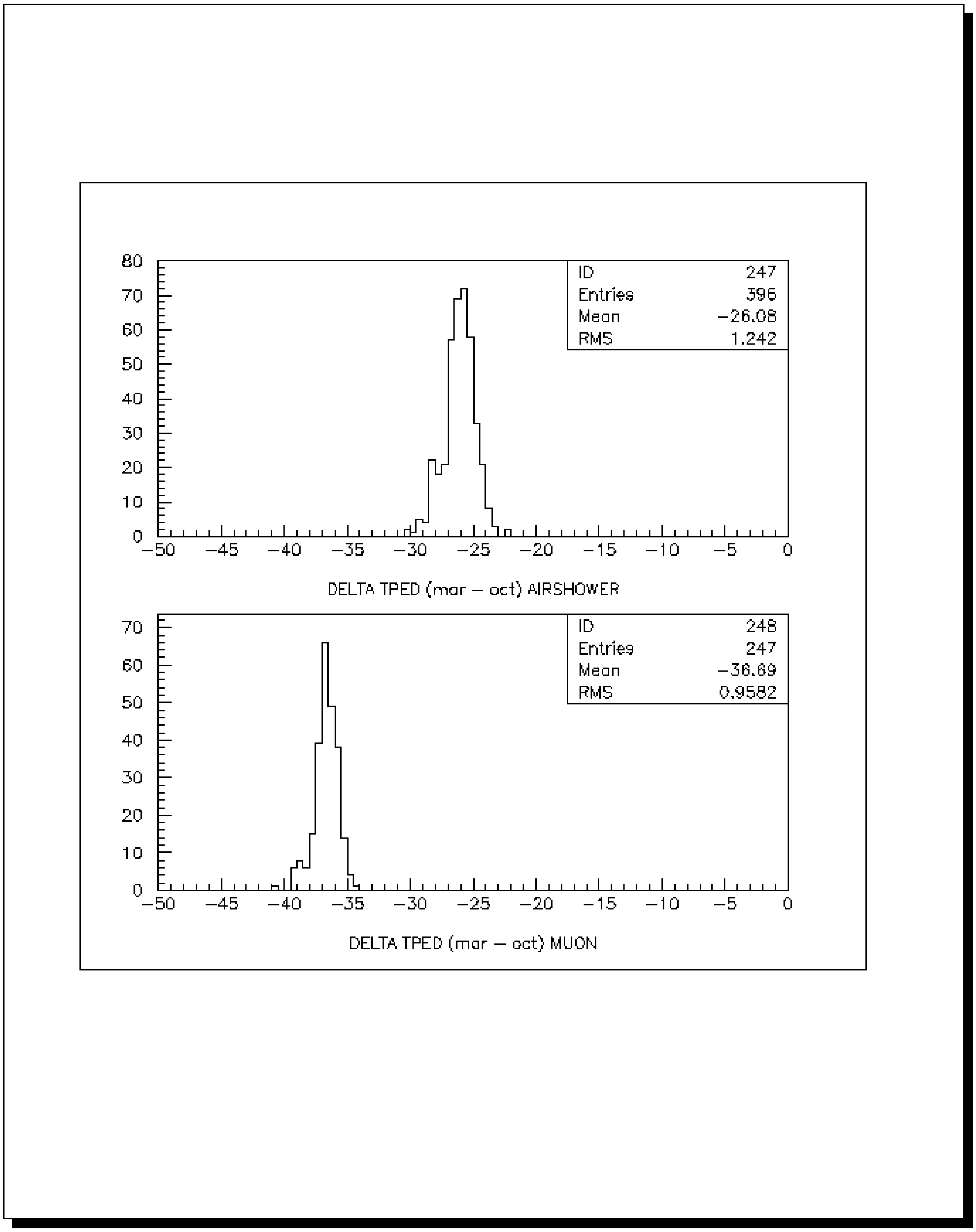

Figure 6: Time Pedestal Drifts by Layer; MAR vs OCT.

- RMS Drift=1.3 counts for NOV - OCT
- RMS Drift=1.2 counts for MAR - OCT (AS)
- RMS Drift=0.9 counts for MAR - OCT (MU)

Apparently the RMS drifts are no worse across five months than across one month. Finally, our analysis of NOV vs OCT data allows us to compare the difference in drifts for LO and HI TPEDS. The distribution of the 4-fold difference,

[TPED(HI,NOV)-TPED(HI,OCT)]-[TPED(LO,NOV)-TPED(LO,OCT)],

shown in Fig. 7 is centered at zero and noticeably narrower than that in Fig.5(a), with mean of 0.06counts and an RMS of 0.6counts. The low and hi TPED's tend to drift together.

5 Tilt due to Pedestal Drift.

The most pernicious effect of pedestal drifts can be a resulting change in reconstructed direction. We test for such a tilt directly by fitting a plane to the MAR to OCT pedestal differences, using the x-y coordinates of the PMT's, to look for a deviation in angle. We tabulate the tilts below, in pond-oriented coordinates (x' and y'):

- AS : theta(x')=$-0.21°$ theta(y')=$+0.14°$
- MU: theta(x')=$-0.20°$ theta(y')=$-0.05°$

The tilts are worse for the short direction of the pond (x') with it's shorter lever arm for fitting the angle. Although such tilt magnitudes are not deadly, it would have been comforting to find them smaller. The tilts are below our resolution, but not negligible as systemic contributions to mis-pointing.

6 Bad Channels.

Four PMT's are excluded from the calibration files, although alive, because the data showed instability, indicating troubles with the channel. These are 81 (multiple bands in slewing) and 112 (unstable pedestal) in the AS layer, and 495 (rise time a factor of 5 slower than family of all others; large pedestal drifts) and 521(unstable pedestal) in the MU layer.

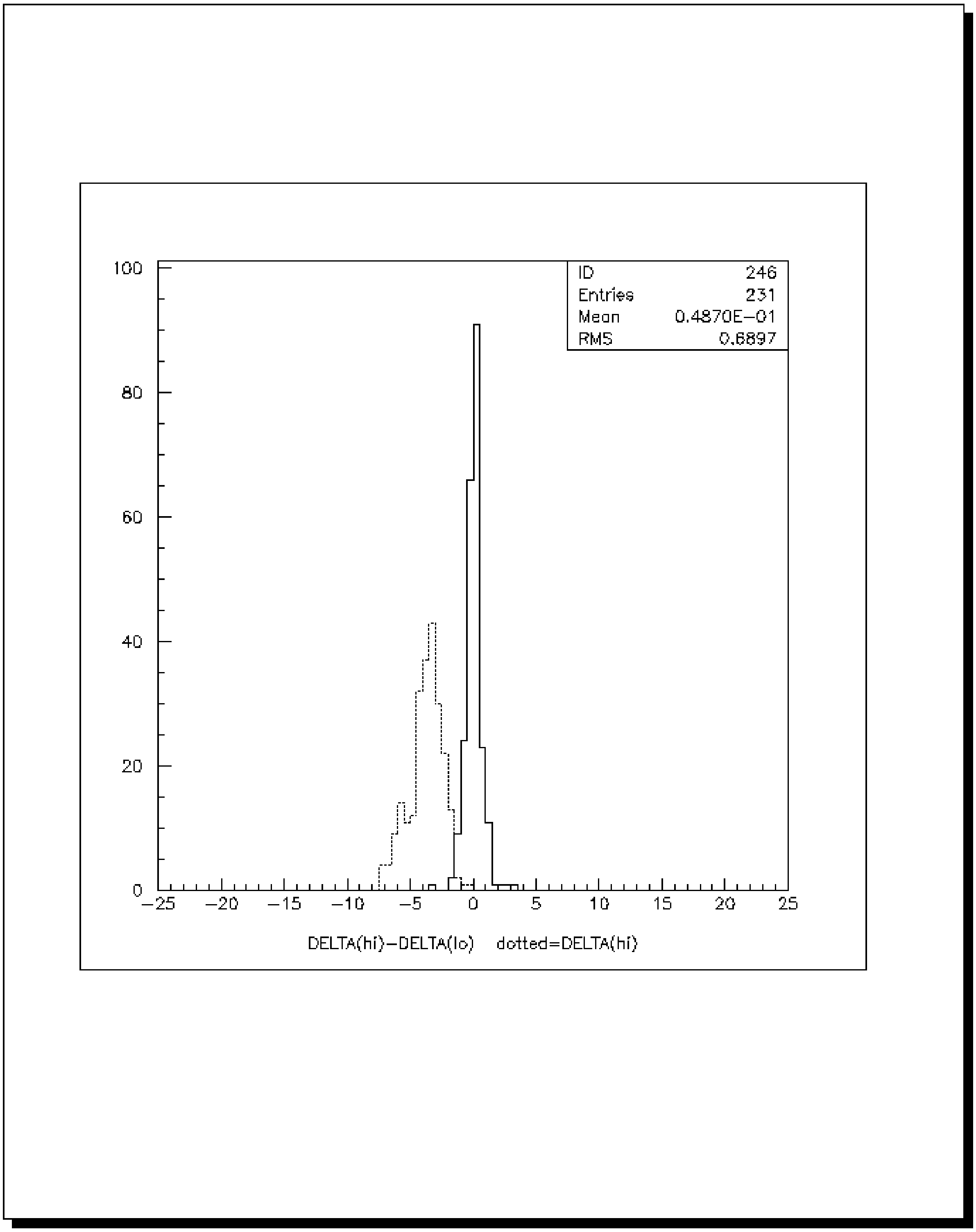

Figure 7: Difference in HI and LO TPED drift. Dotted curve is repeat of Fig.5(a) for ease of comparison.

7 Summary.

We conclude that both slewing shape changes and time-pedestal drifts are characterized by a range of deviations of less than 4counts (2ns) and RMS deviations of less than 2counts (1ns). The resulting tilts, across 5months, in reconstructed direction are on a scale of a fifth of a degree.

The apparently benign, but utterly puzzling layer-dependent 'trigger shifts' are not understood and asking for an explanation.