LED Data Analysis in Air Fill

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1 Introduction

SNO uses a laser source (so called laserball) to calibrate relative timing of each PMT [1]. This time correction is critical for almost all future SNO data analyses, thus it is desirable to have additional optical calibration sources to verify such calibration. Six LEDs deployed by the LBL SNO group provide such opportunities [2]. As PSUP hubs, where LEDs were installed, are the most stable and accurate locations for establishing geometric parameters of the PMT array, positions of these LEDs ahve been determined accurately (within 1 inch).

Validity of PMT time calibration can be checked by comparing reconstructed LED positions with their known positions. Furthermore, certainty of LED positions allow us to check systematic errors in the PMT time calibration due to uncertainty in the laserball position.

2 Reconstruction of LEDs' position

Figure 1 shows a time distribution of PMT hits produced by an LED source. As the LED is pointed roughly at the center of the detector, peak of the distribution corresponds to the time photons hit PMTs opposite to the LED. Entries beyond the peak are mainly hits produced by photons reflected/refracted by the AV and the PSUP. A time cut is necessary to remove these 'late' hits as their number may surpass the number of hits caused by straight-line travelling photons for a particular tube.

A time distribution of hits for a single tube after the cut is shown in figure 2. The distribution has an RMS of 2.58ns, as width of PMT transit time is 1.7ns, ASSUMING ADDING IN QUAD, LED pulse may have a 1.9ns width. In order to minimize reconstruction errors due to these relatively large uncertainties, the peak of a PMT time distribution has to be determined. Following algorithm was used:

1. A 0.5 ns time window is used to scan the whole distribution, the position where the maximum number of entries fall into this time window is reckoned as the rough peak position.

2. An asymmetric time window(+2.5ns, -7.5ns) is imposed around the peak position established in the first step, events falling into this time window are fit

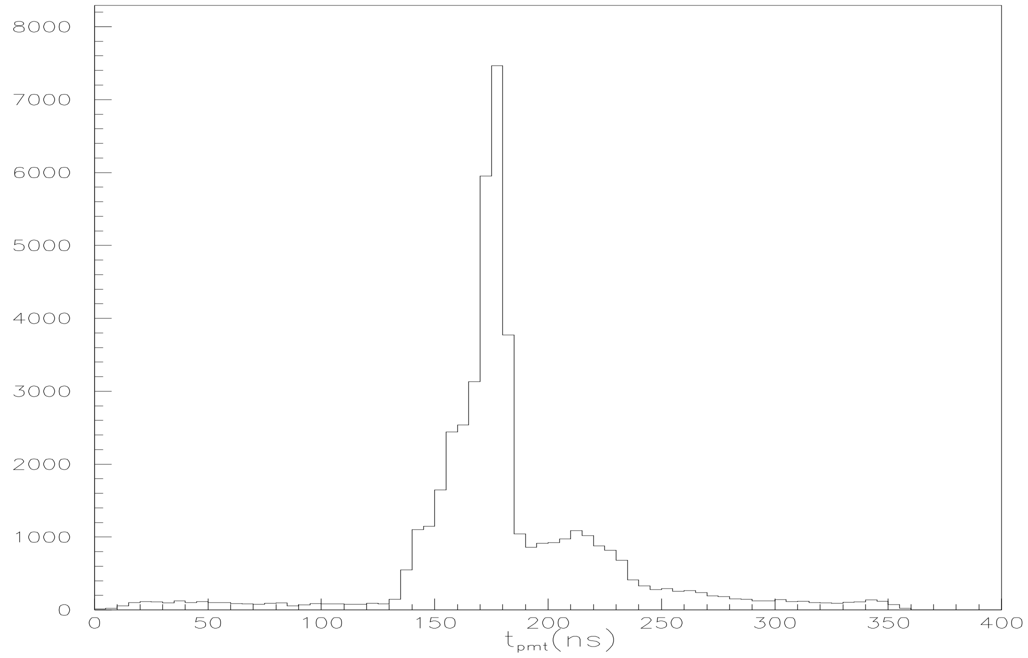

Figure 1: Time distribution of PMT hits produced by an LED source.

to a gaussian distribution in order to determine the peak position more accurately. The asymmetric time window is adopted to minimize effect of skewness of the distribution, due to the fact late hits are more likely than earlier ones, on the fitting.

For the distribution shown in figure 2, the peak position is determined to be 176.88ns. Such procedures were carried out for every PMT with results shown in figure 4. Goodness of fitting (χ^2/DOF) distribution is shown in figure 3. It seems the gaussian distribution fits underlying distribution quite well.

As shown in figure 4, there is a clear turning point at distance $\approx$ 800cm. PMTs less than 800cm away from the LED are not able to see the LED directly, most of photons detected by the tubes come from the reflection of light on the AV so they have larger $t_{distance}$ values. There is also a jump point at distance $\approx$ 1200cm. Beyond this point, the distribution has a slightly negative slope. Photons emitted at different angle may transverse different length of AV and get refracted in the AV-air boundary. Because the light speed in AV is smaller than that in air, photons passing through the AV arrive later than ones missing the AV. In order to minimize these affects, only PMTs with $distance > 1600cm$ or $1200cm > distance > 900cm$ were used in vertex reconstruction (a time fitter was used.), results are shown in table 1. The nominal LED positions [3]is shown in table 2, reconstruction errors isshown in table 3. Generally speaking, a time fitter has its largest reconstruction error along event direction(in this case, LED direction) because of the so-called fitter pull effect. Thus reconstruction errors were divided into two components: parallel and perpendicular to the LED direction. As table 3 shows, perpendicular errors for all (except LED 79) LEDs are small. These errors could be further reduced

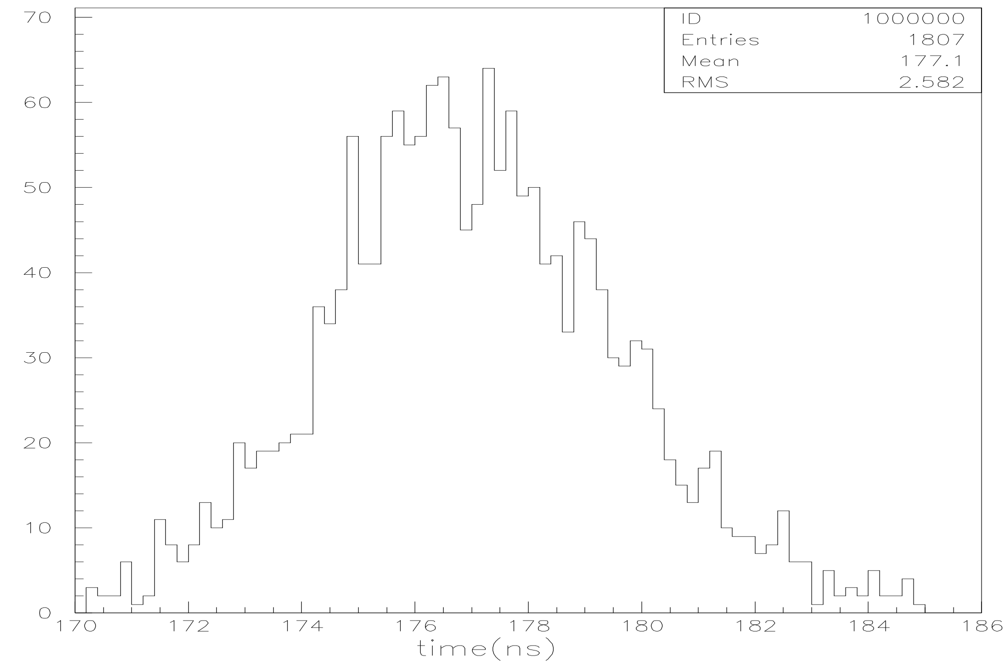

Figure 2: Time distribution of hits for a single tube produced by an LED source.

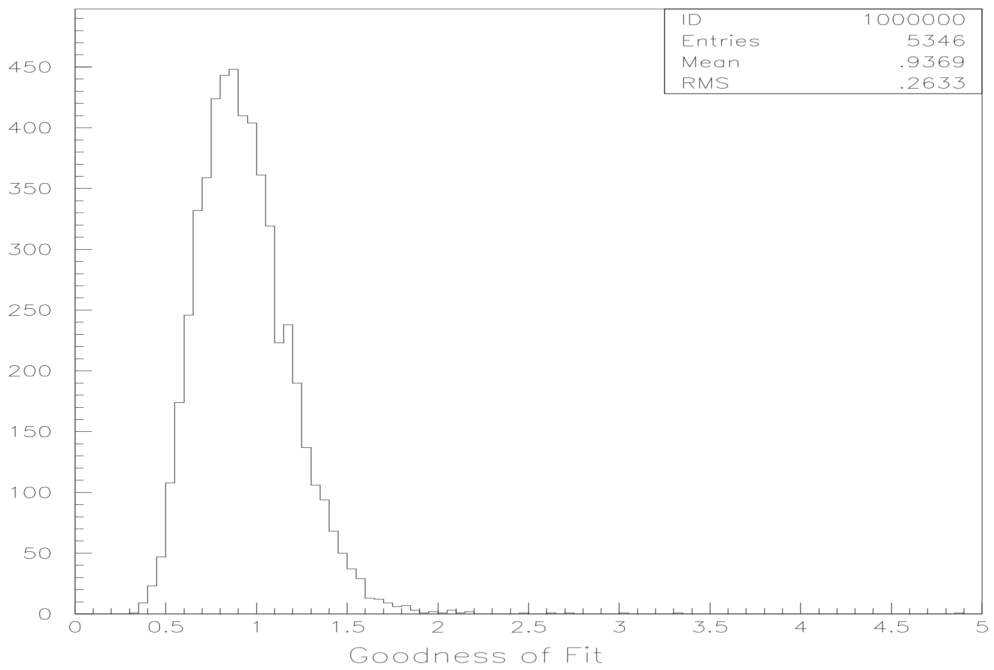

Figure 3: Goodness of fitting the time distribution with an Gaussian. Unit is χ^2 per degree of freedom

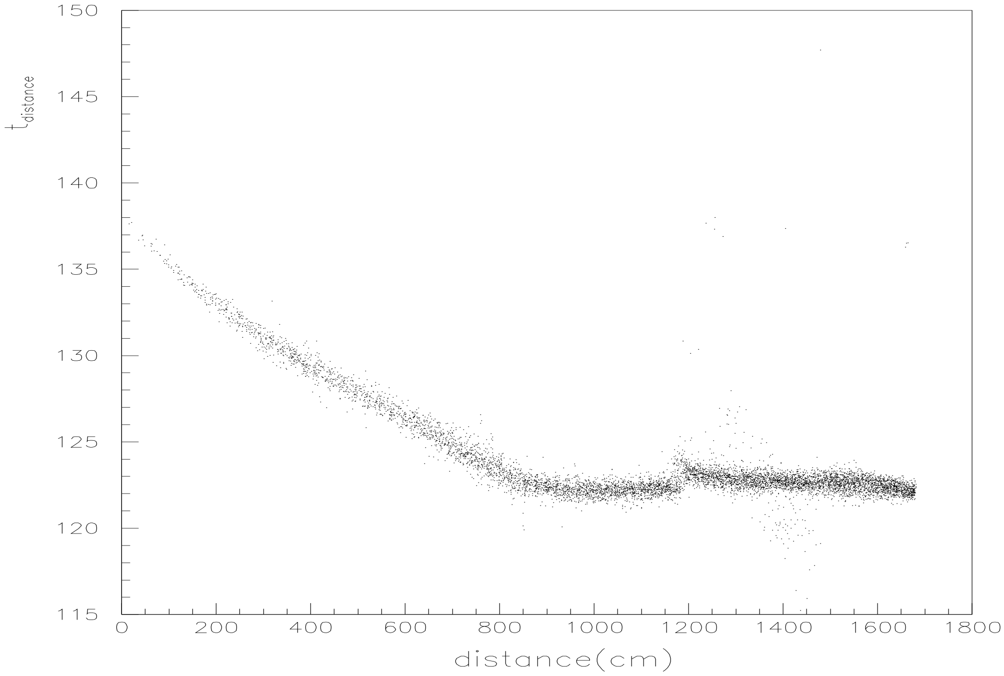

Figure 4: Distance corrected time vs. distance (between the LED and PMT) plot for all PMTs illuminated by the LED. Every entry in the plot corresponds to a PMT. $t_{distance} = t_{pmt} - distance/v_{light}$.

by taking into account difference in path length a photon needs to pass through the AV before hitting a PMT. All fit vertices (except LED25) were "pulled" away from their nominal positions, relative to the AV center. This may be because the asymmetric window imposed on the time distribution doesn't get rid of all of the late hits which pushed fit vertices away from impact areas. There might be another important reason: nominal laserball position is lower than its real position relative to the PSUP center. As electronics delay of each PMT is corrected according to laserball position, if the laserball position is wrong, the whole coordinate system, in views of $\approx$ 10000 PMTs, will be shifted. Thus fit position of LED25, the only LED located at the upper hemishpere of the detector is somewhat pulled down. LED79 and LED55 are the two LEDs with large longitudinal errors. As shown later, light from these LEDs have very strange angular distributions.

3 Reconstruction of Laserball's Position

Laserball position is used in PCA codes to calibrate various delays(cable delays, electronics delay ...), thus any errors in the laserball position will be propagated to any SNO data analyses using PMT time information. As LED positions are quite certain, we could carried out the same PCA procedures using LEDs instead of the laserball as the light source. Electronics delays for various tubes calibrated by LED 45 is shown in figure 5. In order to check consistency of the algorithm, delays for tubes calibrated by different LEDs were compared with results shown in figure 6.

Table 1: Fit vertices for 6 LEDs (In PCA, (9,-25,8.25) is used as laserball position instead of nominal one(9,-25,0))

LED no.	Fit X (cm)	Fit Y(cm)	Fit Z(cm)
71	714.36	48.29	-484.51
45	-693.59	55.33	-469.62
35	-157.04	689.75	-473.97
55	-12.88	-804.13	-371.92
79	52.21	0.33	-892.56
25	682.82	243.48	374.22

Table 2: True vertices for 6 LEDs [3].

LED no.	Fit X (cm)	Fit Y(cm)	Fit Z(cm)
71	697.53	53.55	-463.39
45	-698.98	49.13	-461.54
35	-162.43	680.63	-463.11
55	-8.15	-764.21	-346.11
79	37.01	1.45	-838.32
25	694.94	248.12	399.35

Table 3: Reconstruction errors

LED no.	Longitudinal Error(cm)	Perpendicular Error(cm)
71	+25.33	10.19
45	+0.32	11.59
35	+12.36	8.25
55	+47.06	8.42
79	+54.85	13.37
25	-23.37	15.64

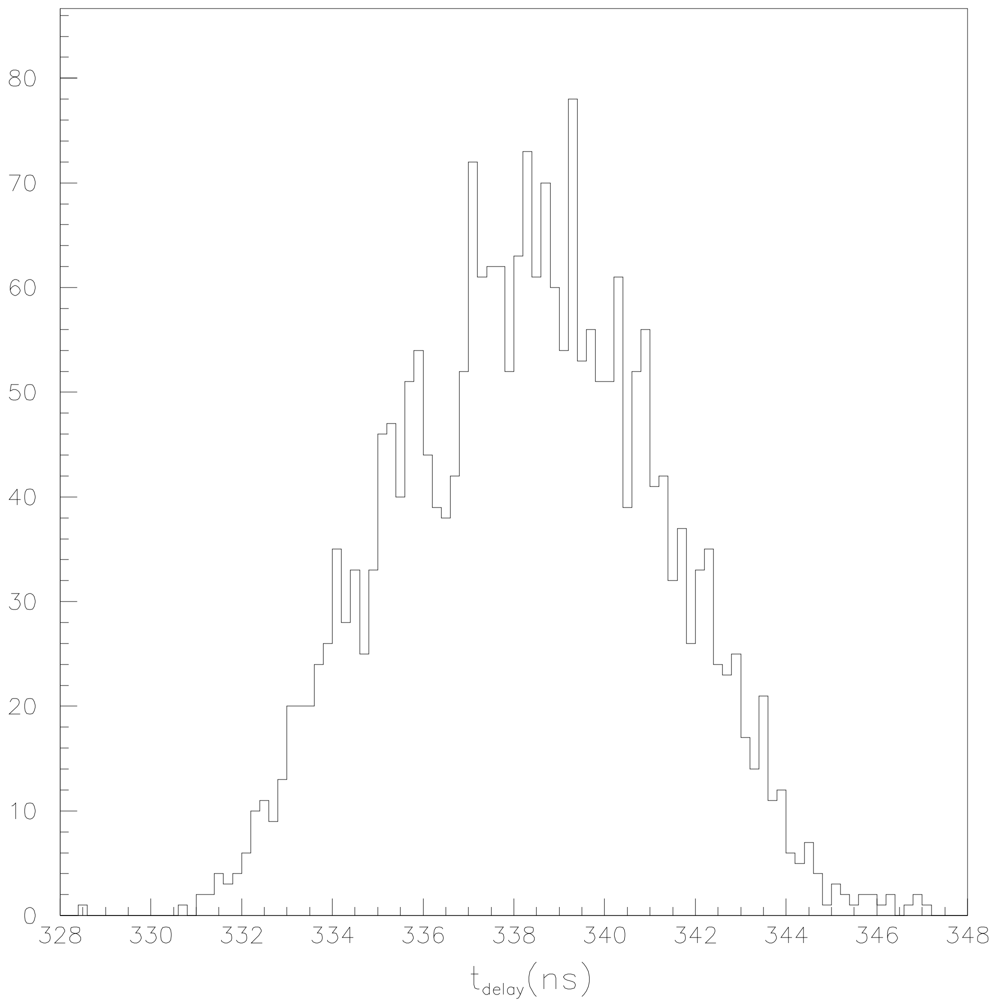

Figure 5: Electronics delays of various PMTs calibrated by LED45

Note the distribution is not centered around 0, its peak position corresponds to the differennce in source time between the two LEDs.

We can then reconstruct laserball position using tubes calibrated by the LEDs. Such procedures have been carried out and results are shown in table 4. As a single LED can only calibrate PMTs located at a limited area opposite to itself, reconstruction of laserball also suffers from the fitter pull effect. In order to reduce such effects, more than one LED has to be used in the reconstruction. the LEDs' relative positions are shown in figure 7. Using tubes calibrated by two LEDs should minimize reconstruction error as the longitudinal direction of one LED is more or less perpendicular to the other LED's direction. However, there is an additional parameter Δt (difference in source time between two LEDs) to fit as LED's trigger is not synchronized to the detector trigger. Fit results are shown in table 5. Compared with the nominal laserball position (9,-25,0), fit vertices using tubes calibrated by different sets of LEDs are quite consistent with each other and largest difference is

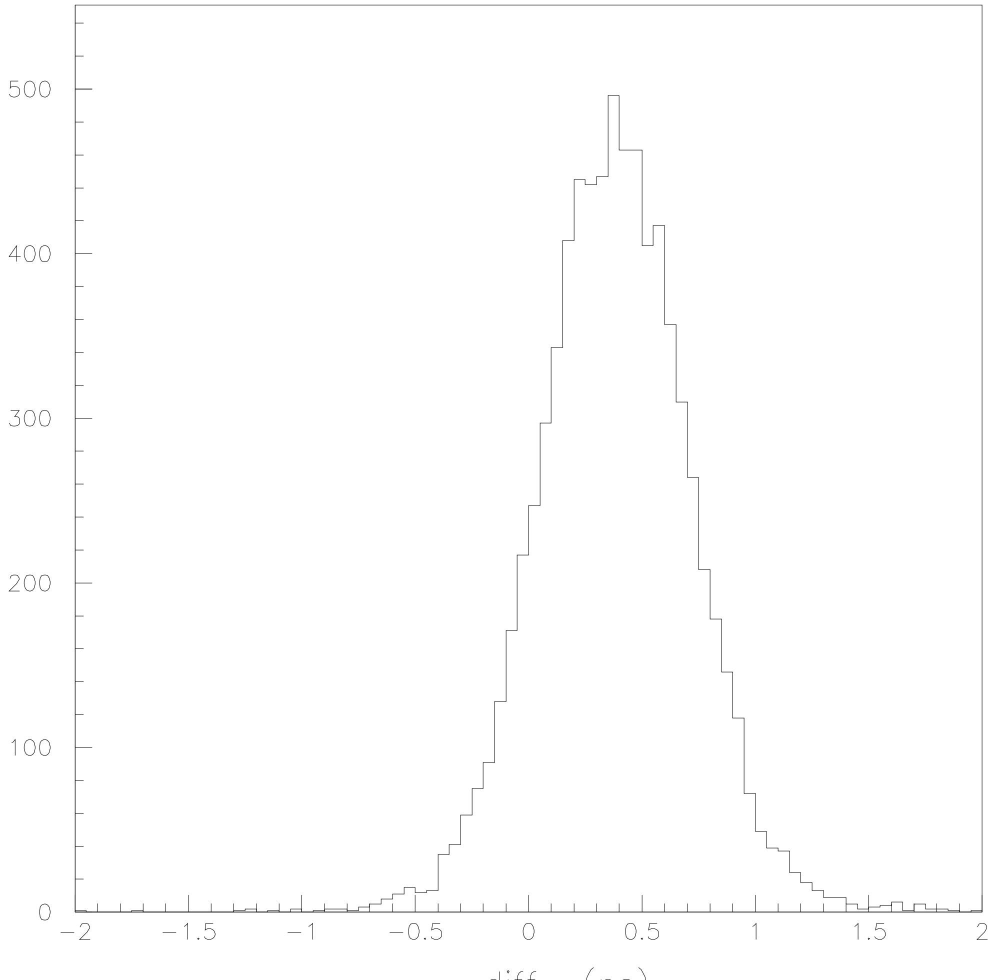

Figure 6: Difference in PMT delay times calibrated by two LEDs

Table 4: Fit vertex for Run998 using tubes calibrated by different LEDs. Nominal laserball position is(9, -25, 0)cm. Tubes more than 1400cm away from the LED were used in reconstruction.

LED no.	Fit X(cm)	Fit Y(cm)	Fit Z(cm)
45	-19.18	-30.91	3.72
35	-1.51	-6.59	2.58
71	30.11	-19.03	3.76
55	4.63	-33.38	14.42
25	8.82	-25.35	23.11

Table 5: Same as table4, using tubes calibrated by two LEDs(distance between PMTs and the LED > 1600cm)

LEDs no.	Angle between 2 nominal LED directions(degree)	Fit X(cm)	Fit Y(cm)	Fit Z(cm)	time difference (ns)
71, 45	113	4.98	-27.34	21.70	0.46
35, 55	121	2.88	-25.35	18.52	-1.071
25, 35	101	5.05	-30.07	24.35	3.00

along the z axis. From this we claim there is a possibility that the AV center doesn't agree with the PSUP center.

4 Light output of the LEDs

As shown in figure 8, LED45, 35 and 71 have distributions as expected: Nhits peaks at the largest distance which means these LEDs point roughly at the center of the detector. However, even at the same distance away from the LED, different tubes have quite different Nhits. It may be because:

- LEDs are not pointed exactly at the detector center.
- Different tubes have different gains.
- Some of light pass through belly plates of the AV.

The effect of the AV can also be seen in these plot; Nhits drops across distance $\approx$ 1200cm.

The distribution from LED25 is not peaked at the largest distance and its width is quite large. This is a clear indication that LED25's direction deviates away from the AV center. The distributions produced by LED55 and LED79 are very odd: they have two instead of one peak which can not be explained by error on LED direction. Furthermore, photons in the two peaks hit PMTs roughly at the same time so the observation can't be explained by possible reflection or refraction either.

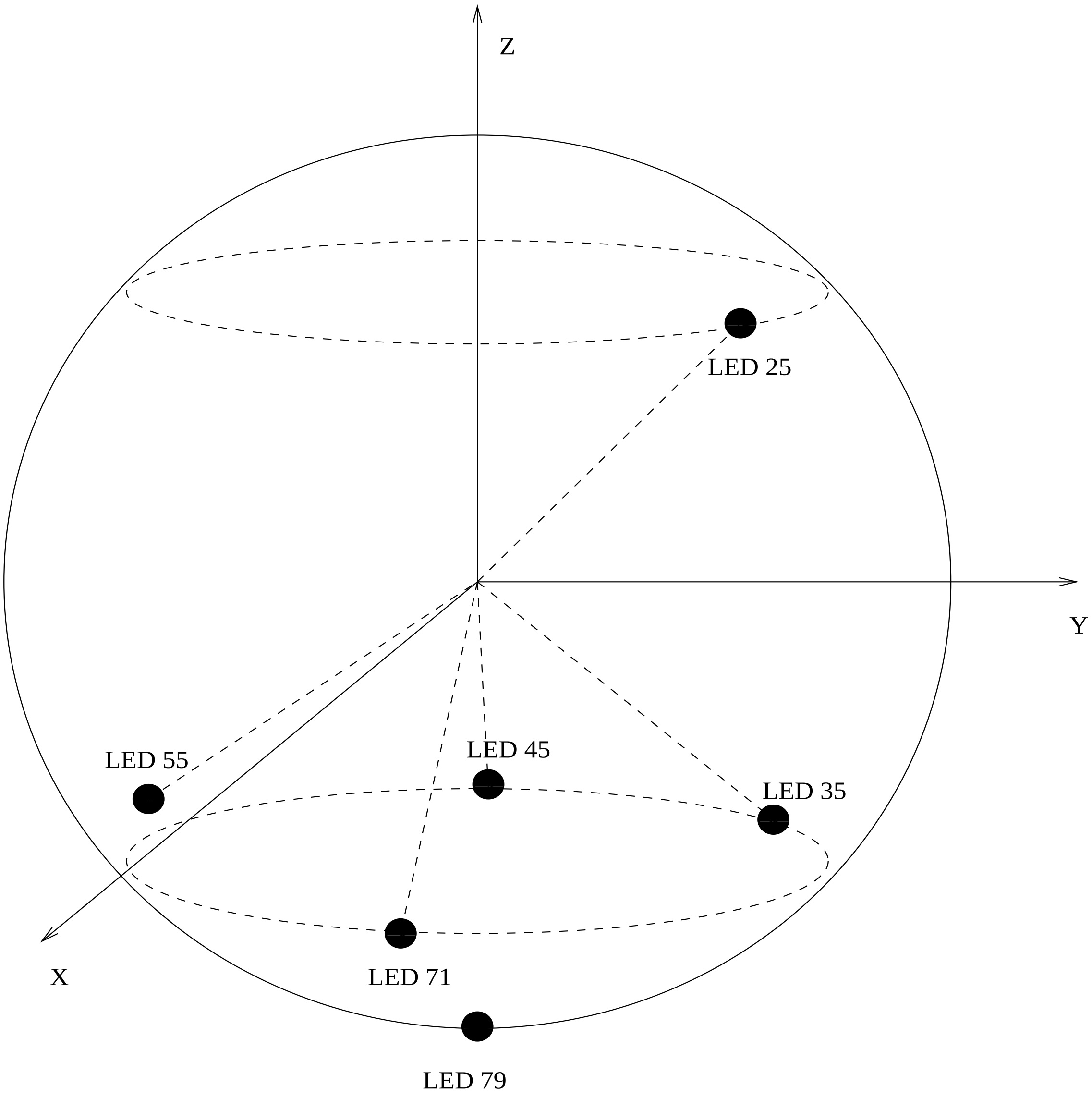

Figure 7: LEDs' position in the detector

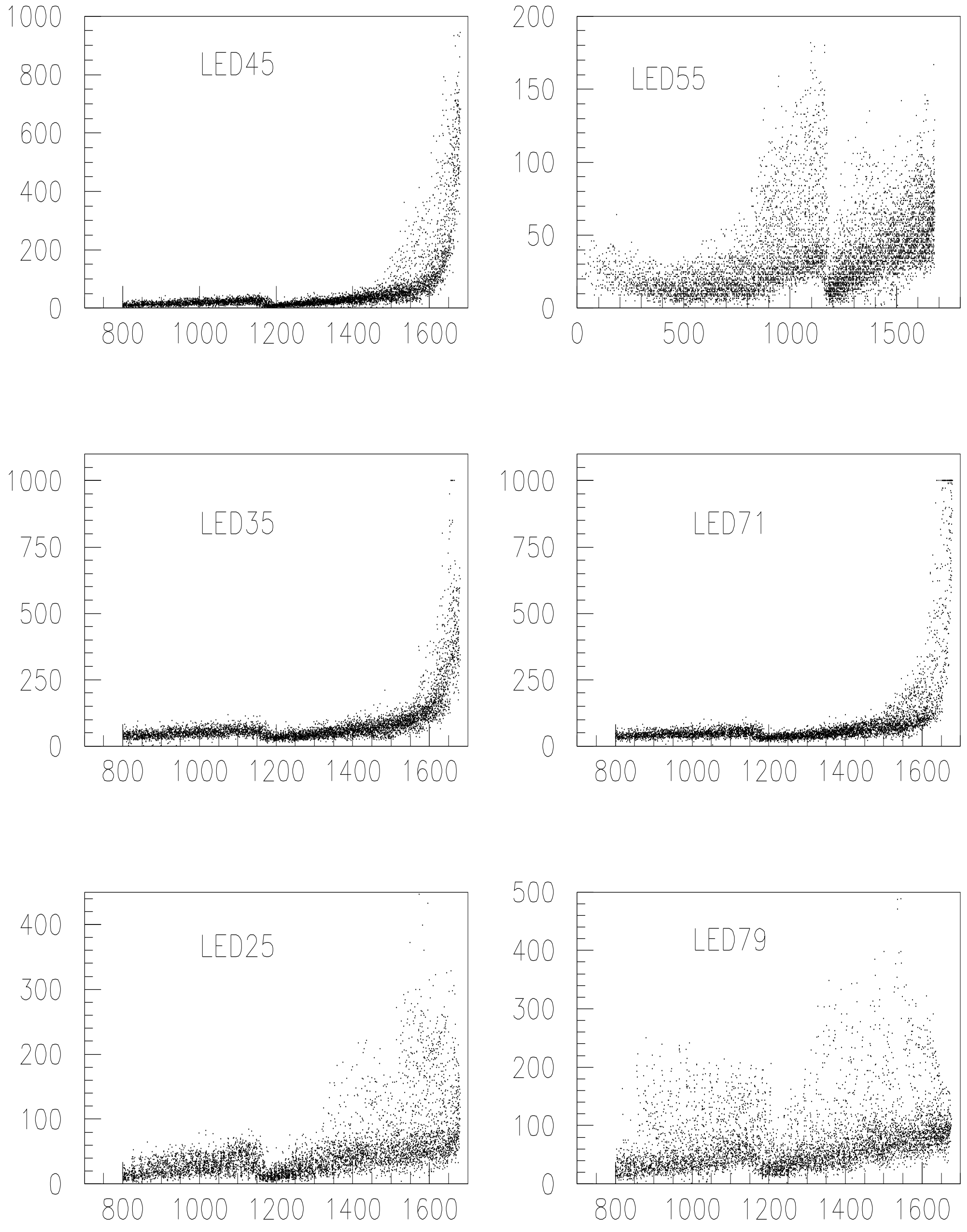

Figure 8: Nhits(vertical axis) vs. Distance between PMT and LED(horizontal axis) distribution. Each entry corresponds to a single PMT.

5 Conclusion

All (except LED79) LEDs were reconstructed fairly close to their nominal positions, which should give us more confidence on the PCA processor. Using tubes calibrated by LEDs, laserball was reconstructed roughly 20cm above its nominal position, which indicates a mis-alignment of the AV and the PSUP. Angular distributions of light from LED55 and LED79 are hard to explain unless there are some problems in LEDs

References

[1] Richard. J. Ford, Calibration of SNO for the Detection of ^8B Neutrinos, Ph.D thesis, Queen's university, 1998.

[2] LBL SNO group, Development of the LED optical calibration devices mounted on the PSUP, SNO-STR-1997-047.

[3] Kevin Lesko, Alan Poon, Colin Okada, Gary Koehler. Determining the Position of the PSUP LEDs, SNO-STR-99-004, 1999.