Timing Pedestal Shifting and the Crab

Milagro Note
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This note describes some results of a proposed timing pedestal (TPed) shift applied to all PMTs prior to creating REC data files. The purpose of applying a TPed shift is to try to correct for slight timing miscalibrations, which are seen via TChi distributions where peaks are off-zero. TPed-shifted REC files were created for Crab data from September 2003 to October 2004. Improvements are seen when applying TPed shifts to the PMTs.

TPed Shifts

An example of a very poorly calibrated PMT is shown below. Notice that the TChi peak is well off from zero in this case. Nearly all other PMTs do have good TChi distributions though, sometimes only off by roughly 0.5 to 1 ns.

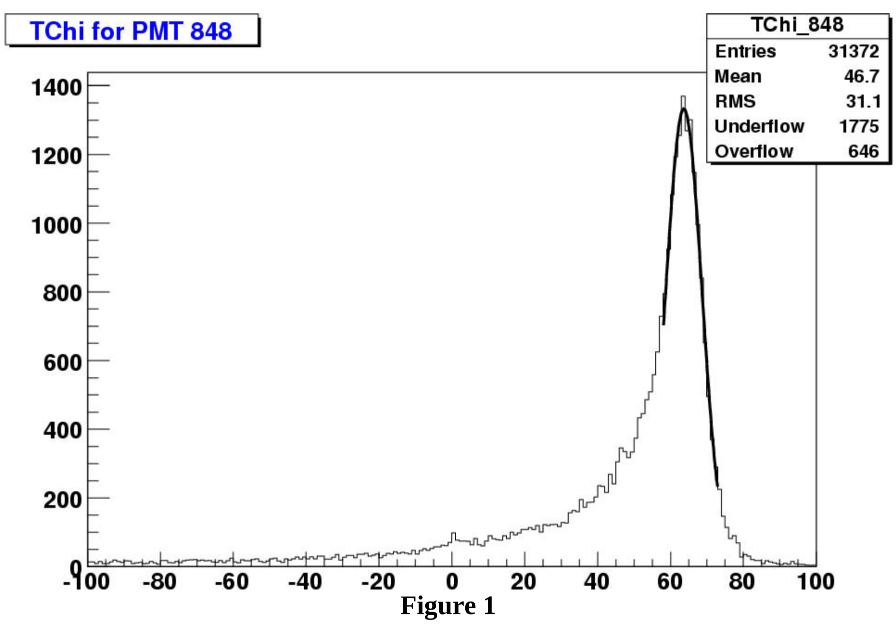


Figure 1
TChi distribution before applying a TPed shift.

The raw events are reconstructed and the TChi peak for each PMT is fit to a Gaussian to determine the peak's mean position. The peak position (time) for each PMT is stored in a text file. The code to create the TPed shift files require a minimum of

50,000 events for a run. A single sub-run usually has more than enough statistics, so only 300,000 events are asked for at most during processing to save time.

As a reminder, TChi is defined as the difference in the shower plane fit expected time and the individual PMT's measured time. The measured hit time for a PMT is the pedestal time minus the TDC output time

$$time = \alpha - TDCtime \tag{1}$$

If the TChi peak is positive in time, then the hits were typically too early. If the peak is negative in time, then the hits were usually too late. We need to make the hits later in the first case, and earlier in the second. This is done by adding the peak time to the pedestal time such that

$$time = (\alpha + PeakTime) - TDCtime \tag{2}$$

A second reconstruction is done next, where the calibrated hits are shifted by the peak times stored in the text file. Doing this for every PMT seems to yield better TChi distributions. It corrects PMT 848 (outrigger 96) well, as shown in Figure 2.

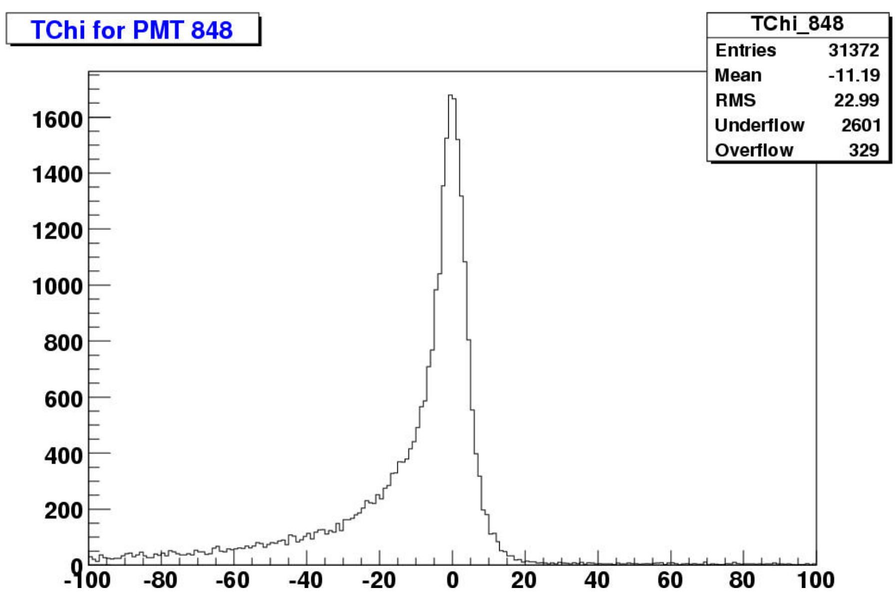


Figure 2

TChi distribution after applying a TPed shift.

Crab Reconstruction and Analysis

Crab data from September 2003 to October 2004 were reconstructed using only the air shower and outrigger PMTs in the angle and core fitting, and TPed shifting was applied for each PMT. TPed shift files were created for each run number, which corresponds to basically once per day of data. A minimum of 50,000 and a maximum of 300,000 events were used per run to create the shift files. If a particular run did not meet the required number of events such that no shift file was produced, then the reconstruction of that run checked for a valid shift file from the next older run until one was found.

Analysis was done based on the standard Milinda sky mapping code (see Milinda example 'dcsearch'). The sky maps were written to a summed map file after every integration interval (2 hours). 416 solar days of Crab data were examined. Summed sky maps were made for various cuts. The data were heavily oversampled since the unsmoothed sky maps were binned in 0.1°x0.1°, while the analysis presented here was done in up to 1.3°x1.3° bins.

The reconstruction of the same data before the January 2005 collaboration meeting was done with all three layers of PMTs used in the fit and no TPed shifting. The Crab results were presented at that meeting, and they are compared here to the new results.

Crab Results

Table 1 lists the results of looking at the Crab bin (83.6° and 22° in right ascension and declination) for the old reconstruction (3 layer fits) while Table 2 has results from the new reconstruction (AS+OR, TPed shifted). The MARS model is the 12 parameter model, as mentioned in my January 2005 collaboration meeting talk. For more information on MARS, see the October 2004 memo. The significances are found via Li-Ma Eq. 17.

Table 1

	nFit>80	nFit>80, x2>2.5	MARS (on>1, off>2.5)	MARS (1, 0.6)	MARS (0.8, 0.8)
Significance	2.65	4.56	2.66	3.62	3.27
On Source	2212841	240608	24681	69100	61763
Off Source	2208997.25	238434.3	24275.41	68177.84	60973.69
Excess	3843.75	2173.7	405.59	922.16	789.31
FracExcess	0.00174	0.00912	0.01671	0.01353	0.01295

	nFit>150	nFit>150, x2>2.5	nFit>150, x2>5
Significance	2.4	3.13	4.19
On Source	88484	51681	12594
Off Source	87753.91	50953.76	12117.9
Excess	730.09	727.24	476.1
FracExcess	0.01	0.01	0.04

This table uses nTop>55 for all results in addition to the cuts in the column headers. The numbers are from the old reconstruction which uses all PMTs in the fits and 1.3° square bins.

Table 2

	nFit>20, x2>2.5	nFit>30, x2>2.5	nFit>40, x2>2.5	nFit>50, x2>2.5	nFit>60, x2>2.5	nFit>70, x2>2.5	nFit>80, x2>2.5
Significance	5.14	5.22	5.17	4.99	4.41	4.75	4.43
On Source	99939	97982	91352	79186	65890	53828	43361
Off Source	98281.22	96313.71	89757.55	77754.68	64734.43	52705.4	42420.38
Excess	1657.78	1668.29	1594.45	1431.32	1155.57	1122.6	940.62
FracExcess	0.01687	0.01732	0.01776	0.01841	0.01785	0.02130	0.02217
	nFit>20	**nFit>30**	**nFit>40**	**nFit>50**	**nFit>60**	**nFit>70**	**nFit>80**
Significance	5.15	5.12	4.94	4.72	4.00	4.31	4.00
On Source	160723	156530	144116	125701	108504	93922	81471
Off Source	158614.36	154459.64	142201.09	123990.27	107156.91	92574.05	80305.67
Excess	2108.64	2070.36	1914.91	1710.73	1347.09	1347.95	1165.33
FracExcess	0.01329	0.0134	0.01347	0.0138	0.01257	0.01	0.01451
	nFit>150	**nFit>150, x2>2.5**	**nFit>150, x2>5**	**nFit>150, x2>6, x2cx>6**			
Significance	3.32	5.05	4.43	4.32			
On Source	37402	8465	1980	942			
Off Source	36746.34	7997.51	1784.38	812.33			
Excess	655.66	467.49	195.62	129.67			
FracExcess	0.02	0.05845	0.10963	0.16			
	MARS (1, 2.5)	**MARS (1, 0.6)**	**MARS (0.8, 0.8)**				
Significance	3.52	4.16	4.35				
On Source	22326	46340	45423				
Off Source	21790.49	45426.55	44478.4				
Excess	535.51	913.45	944.6				
FracExcess	0.02458	0.02011	0.02124				

These are results from various cuts while requiring nTop>55 and MARS cuts of (0,0). This makes use of the new reconstruction. x2cx is nb2/cxPE. The bin size is 1.3°.

A direct comparison between the two different reconstructions is only valid for the results using MARS (on>1, off>2.5), (1, 0.6), and (0.8, 0.8). This is due to the nFit cut values meaning different things when using a 3 layer versus a 2 layer fit. A direct determination of the effect of TPed shifting is discussed in the next section.

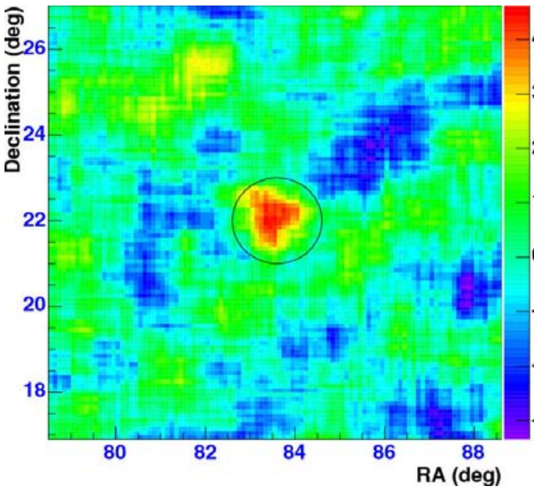
The new reconstruction with TPed shifting seems to do well. The MARS (on>0.8, off>0.8) cut scheme gives a fractional excess of 2.1% with a significance of 4.35σ in the Crab bin. This is compared to a fractional excess of 1.3% with a significance of 3.27σ using the same MARS model and cuts on the old reconstruction. This means a Q-factor increase of 1.3 is obtained just from the different reconstruction and the use of TPed shifting.

For the largest events presented here (nFit>150, x2>6, x2cx>6, MARS (0,0)), the signal to background ratio is 16% while the significance is ~4.32σ in the Crab bin. This is with a square bin size of 1.3°. Other bin sizes ranging from 0.4° to 1.2° in 0.1° steps are also examined. The optimal bin size for this sample of events turns out to be 0.7°, as it gives the highest significance of 5.23σ (see Table 3). Crab sky maps are shown in Figure 3 and Figure 4 for 1.3° and 0.7° bin sizes.

Table 3

	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°	1.0°	1.1°	1.2°	1.3°
Significance	4.1	4.11	5.22	5.23	4.64	4.65	4.66	5	4.31	4.32
On Source	149	149	285	285	431	431	431	622	942	942
Off Source	103.99	103.81	204.75	204.43	340.29	339.93	339.56	502.8	812.87	812.33
Excess	45.01	45.19	80.25	80.57	90.71	91.07	91.44	119.2	129.13	129.67
FracExcess	0.43	0.44	0.39	0.39	0.27	0.27	0.27	0.24	0.16	0.16

Searching for optimal bin size for events with nTop>55, nFit>150, x2>6, x2cx>6, and MARS cuts of (0,0). 0.7° gives the highest significance while 0.5° gives the highest signal to background.



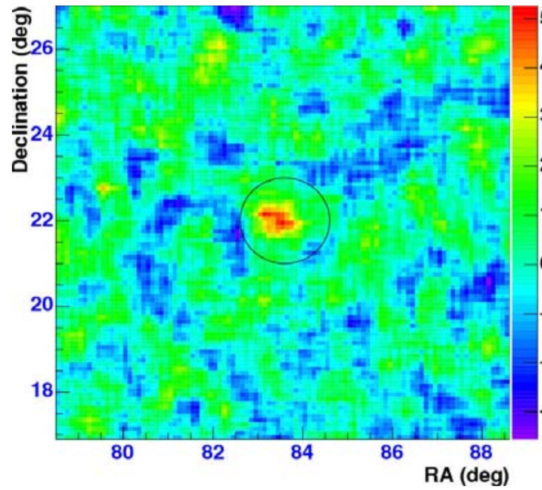
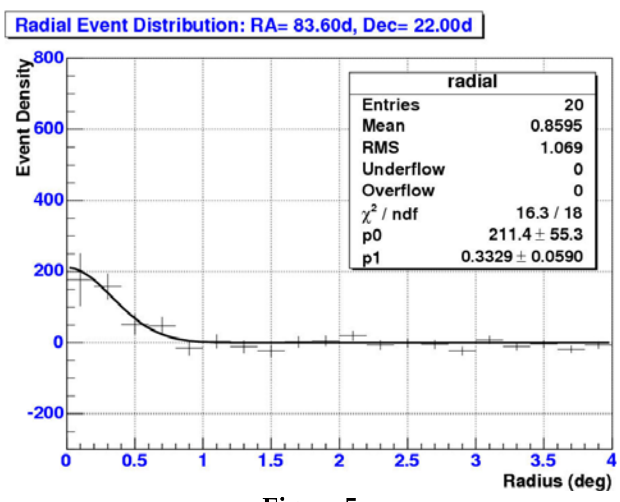


Figure 3 **Figure 4**

Sky maps for the Crab using nTop>55, nFit>150, x2>6, x2cx>6, and MARS (0,0). Figure 3 is for a 1.3° square bin and Figure 4 is for a 0.7° bin.

A Gaussian fit to the normalized radial excess distribution at the Crab bin for these largest events gives an angular resolution of 0.33±0.06°. The maximal bin is centered at a right ascension and declination of (83.15°, 22.15°) and gives a significance of 5.26σ using the optimal 0.7° bin size. Fitting a radial distribution centered at the maximal bin yields an angular resolution of 0.32±0.06°. Figure 5 and Figure 6 are histograms of the radial distributions for these two positions. The distributions are made by reading the unsmoothed sky and background maps and summing events in concentric rings, then normalizing by the area within each ring.



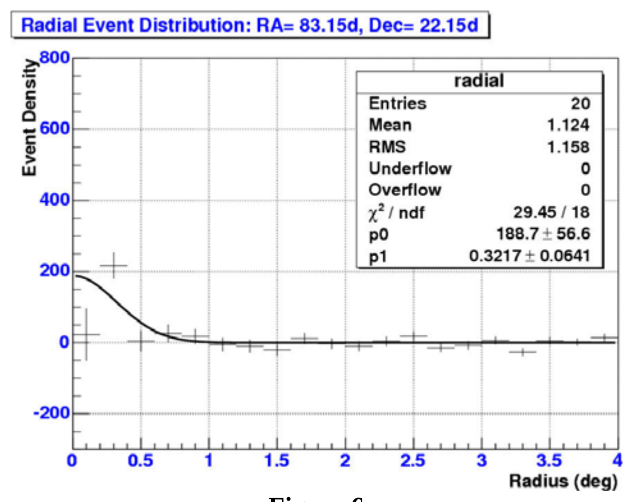


Figure 5 **Figure 6**

Radial distributions and fits corresponding to events with nTop>55, nFit>150, x2>6, and x2cx>6.

AS+OR Only – No TPed Shifts

A direct comparison of the old reconstruction and new reconstruction results is made difficult due to the use of muon layer PMTs in the fits in the former case, but not in the latter. To see the effect of TPed shifting alone, it was necessary to run another reconstruction of the Crab data using just the AS and OR PMTs in the fits and without applying the TPed shifts. Table 4 shows the results on the Crab without TPed shifting using a specific set of cuts and examining different bin sizes.

Table 4

	0.4°	**0.5°**	**0.6°**	**0.7°**	**0.8°**	**0.9°**	**1.0°**	**1.1°**	**1.2°**	**1.3°**
Significance	2.26	2.27	2.17	2.18	3.62	3.63	3.64	3.43	3.5	3.51
On Source	151	151	279	279	478	478	478	689	1089	1089
Off Source	124.66	124.56	243.84	243.7	401.9	401.59	401.28	600.9	974.84	974.37
Excess	26.34	26.44	35.16	35.3	76.1	76.41	76.72	88.1	114.16	114.63
FracExcess	0.21	0.21	0.14	0.14	0.19	0.19	0.19	0.15	0.12	0.12
	1.4°	**1.5°**	**1.6°**	**1.7°**	**1.8°**	**1.9°**	**2.0°**	**2.1°**	**2.2°**	**2.3°**
Significance	3.52	3.97	3.51	3.51	3.52	3.09	3.1	1.76	1.61	1.61
On Source	1089	1427	1768	1768	1768	2143	2143	2521	2977	2977
Off Source	973.9	1277.97	1619.96	1619.34	1618.72	1997.58	1996.96	2429.93	2886.12	2885.73
Excess	115.1	149.03	148.04	148.66	149.28	145.42	146.04	91.07	90.88	91.27
FracExcess	0.12	0.12	0.09	0.09	0.09	0.07	0.07	0.04	0.03	0.03

Bin size scan with nTop>55, nFit>150, x2>6, x2cx>6, and MARS (0,0). No TPed shifting was done for this AS+OR only reconstruction, unlike in Table 3.

Significances are lower here than when using TPed shifting by roughly 1 to 2σ. The signal-to-background ratios are also lower in the Crab bin. This suggests TPed shifting has a positive impact on Milagro's pointing accuracy. However, a comparison of Table 3 and Table 4 shows that TPed shifting decreases on-source and off-source events in most bins by up to roughly 10% and 15%, respectively. The smaller bin sizes see less of a change in the signal than the larger sizes. One probably expects the background counts to change very little while the signal should become larger when applying the TPed shift since better pointing is obtained. This unexpected observed behavior is under investigation.

The angular resolution of this AS+OR only reconstruction is shown in Figure 7 to be 0.44±0.08°, which is equivalent to a 1.23±0.23° square bin size.

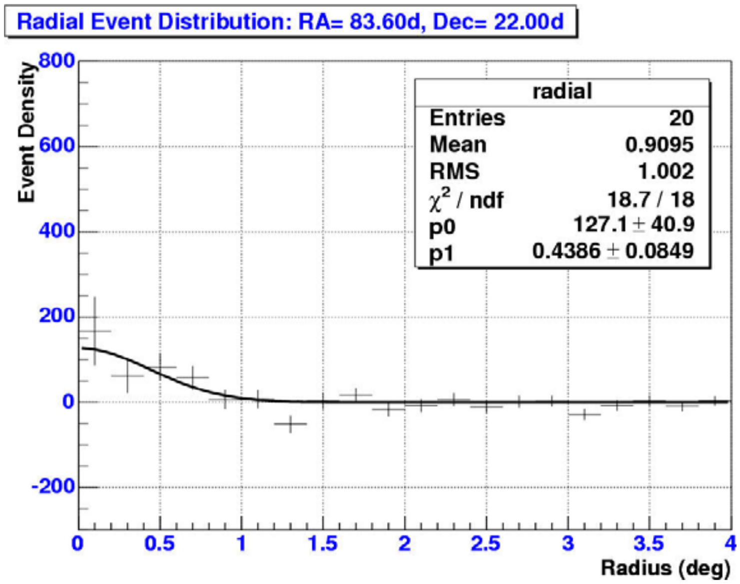


Figure 7
Fit to radial excess distribution for AS+OR only reconstruction.

Conclusion

In the Crab paper, 0.75° was quoted as our angular resolution. This corresponds to a 2.1° optimal square bin size. Including outrigger PMTs in the fits and applying TPed shifts to the PMT hit times appear to produce tighter pointing, at least in high energy events. An angular resolution of 0.33±0.06° is obtained, which corresponds approximately to a 1° optimal square bin size. The optimal square bin size obtained through simply scanning the results of different sizes and searching for the highest significance is 0.7°. This corresponds to an angular resolution of 0.25°.

To determine how much of an effect TPed shifting has on the reconstruction, the Crab was examined with only AS and OR PMTs used in the fits and without TPed shifts. Comparing results for a specific set of cuts (nTop>55, nFit>150, x2>6, x2cx>6, MARS (0,0)), it is clear that the application of TPed shifting results in tighter pointing and thus higher significances and signal-to-background ratios for the Crab.