Milagro Memo
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An Off-Pond Core Finder

Greg Sullivan and Andrew Smith
University of Maryland

Introduction

We describe here a new shower-core fitter that does not constrain the core position to be on the pond. The motivation is to improve the angular resolution of the shower reconstruction by reducing systematic errors in shower direction caused by shower-front curvature effects. When a shower core is off the pond, the curvature of the shower front causes an apparent 4-8 ns/100m "tilt" to the shower. Using the core position, the reconstruction can correct for this effect. However, since the present core fitter is constrained to be on the pond, showers that are off the pond have a systematic error in the reconstructed angle. Because approximately 75-80 percent of Gamma showers triggering the Milagro detector have their core off the pond there is a significant reduction in the sensitivity of the detector. The necessity of knowing the core position to accurately reconstruct the shower direction is the reason for the future construction of outriggers. The new fitter described here attempts to gain back some sensitivity by reconstructing core positions both on and off the pond.

Description of Core Finder

The new core reconstruction described here basically works in the three following steps.

1. The direction of the core relative to the center of the pond is determined.
2. A determination is made whether the core is ON or OFF the pond.
3. If OFF pond, it is placed a fixed radius from the center. If ON pond, the pulse height weighted position of the core is determined

Throughout the core finder only air shower tubes are used at present.

1. Core Direction:

The direction of the core, relative to the center of the pond, is determined in two steps.

- The sqrt(pmt-charge) weighted position of good air-shower tubes is calculated

- The sqrt(pmt-charge) weighted position is again calculated using only air-shower tubes that have their direction cosines within 0.7 of the direction cosine of the above weighted position.

This results in a "provisional" core position.

2. ON or OFF Pond?

Using the direction given by the provisional core from step1, a profile of the average charge per pmt (Q/pmt) versus distance from the center of the pond to the edge of the pond is calculated. This is done as follows:

- The direction is found from step 1
- All pmts with their direction cosines within 0.5 of the direction cosine of the above direction are used to calculate the average Q/pmt in for distance bins
    - Bin 0 is near the center of the pond and inside the provisional core
    - Bin 1 is around the provisional core position
    - Bin 2 is outside the provisional core
    - Bin 3 is the last two rows of pmts
- The four bins of the Q/pmt versus radius are examined to look for ON pond.
    - The Q/pmt is fit to the function: $q/pmt = a + b \times R^2$
    - If the b term is sufficiently negative and the ratio Bin(3)/Bin(1) is small
        - Then ON pond
    - Else
        - OFF Pond

3. Determine Core Position:

The final step is to determine the core position as follows:

- If (ON pond) then
    - Calculate pulse-height weighted position of core using pmts within 8 meters of provisional core
- Else If (OFF pond) then
    - Place core at 50 meters from center of pond in direction of provisional core

Figures 1 and 2 show event displays for Gamma-Ray Monte Carlo events with the actual (yellow square) and fitted (white square) core positions. Figures 3 and 4 illustrate the fact that this core fitter places cores off the pond for most events as expected. In Figure 3 the core position for the old Center-Of-Mass(COM) fitter is shown. In Figure 4 the core position for this fitter is shown.

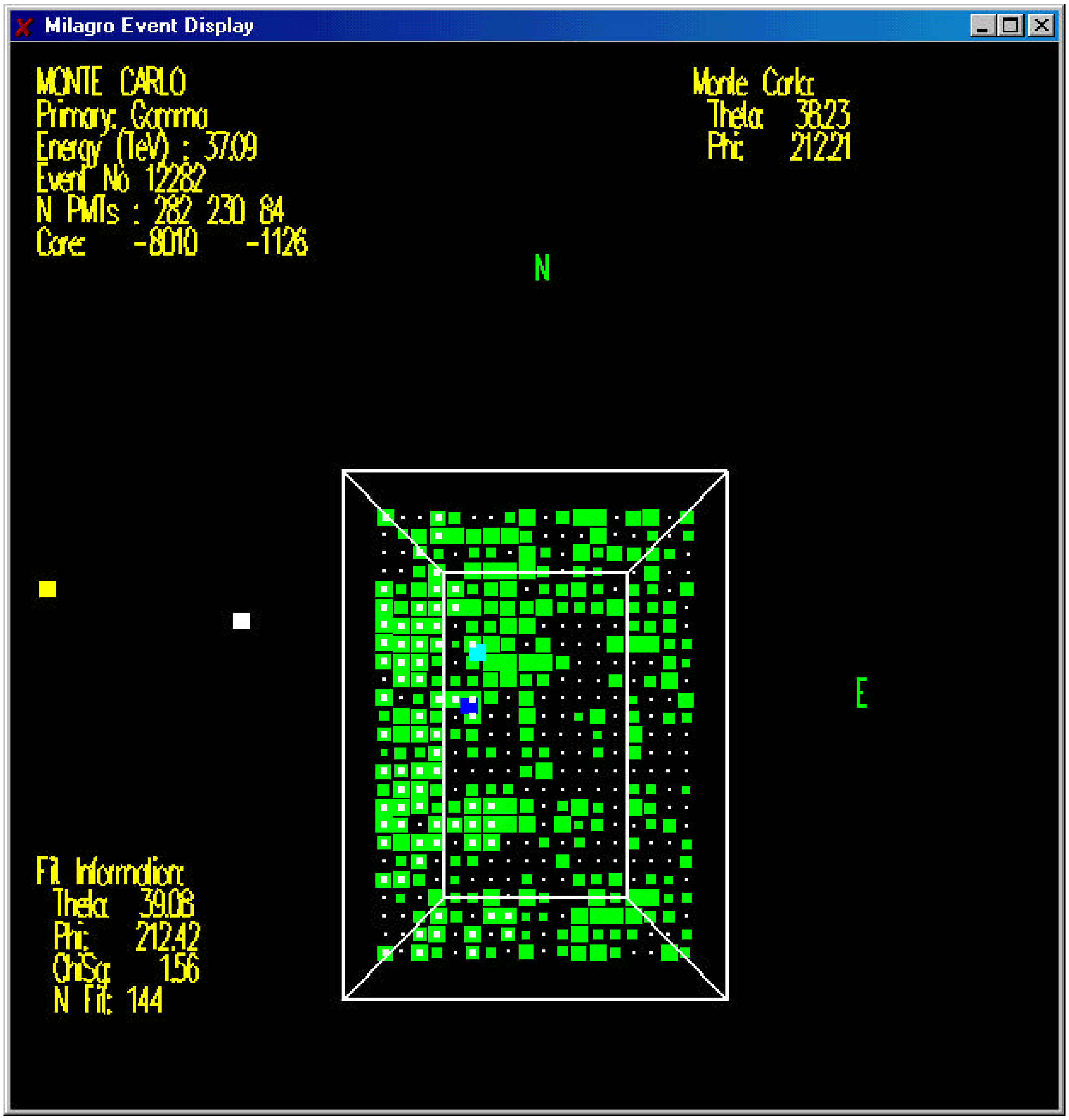

Figure 1 Event Display showing True (yellow) and fit (white) core positions

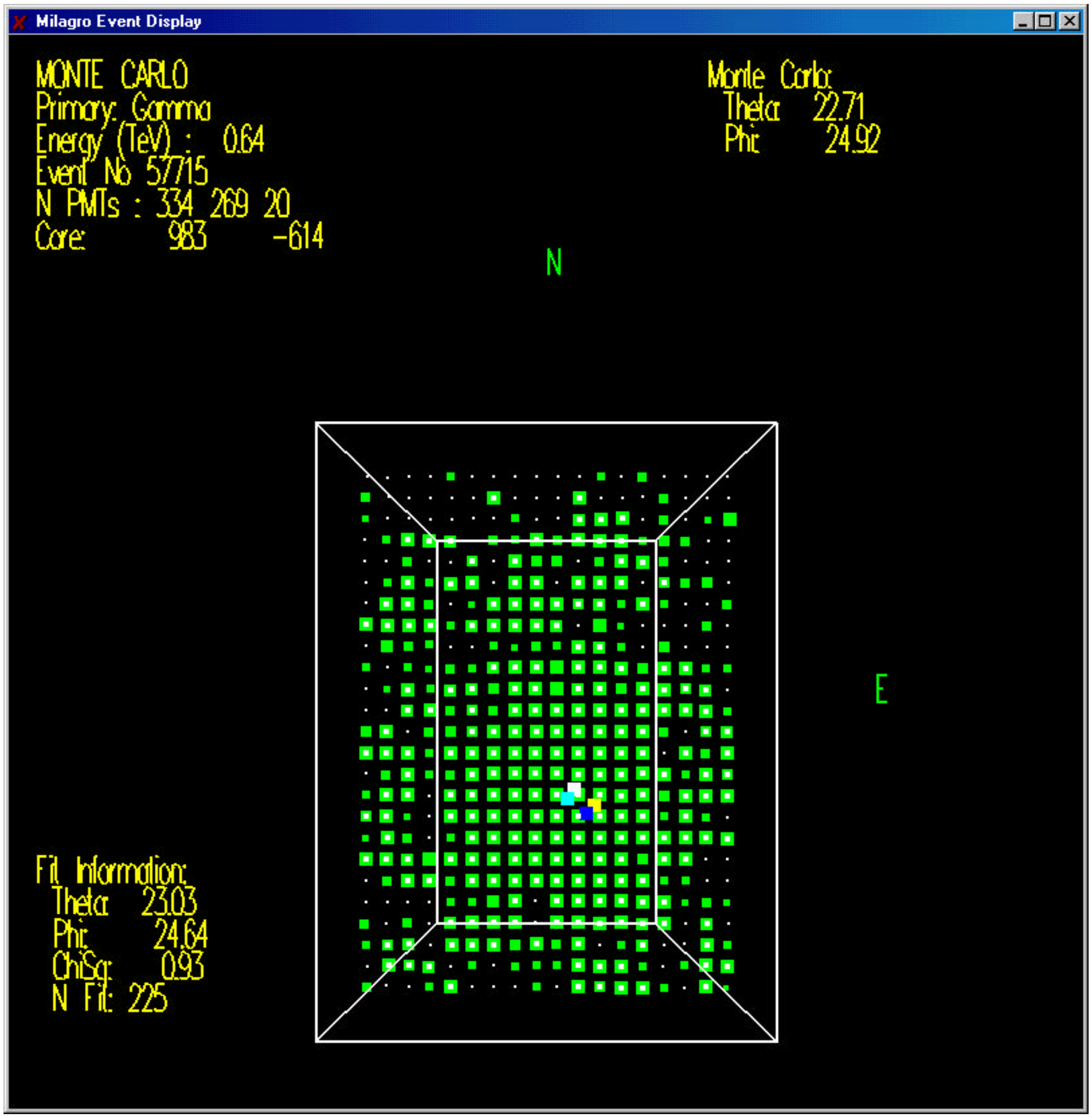

Figure 2 Event Display with True (yellow) and Fit (white) core position.

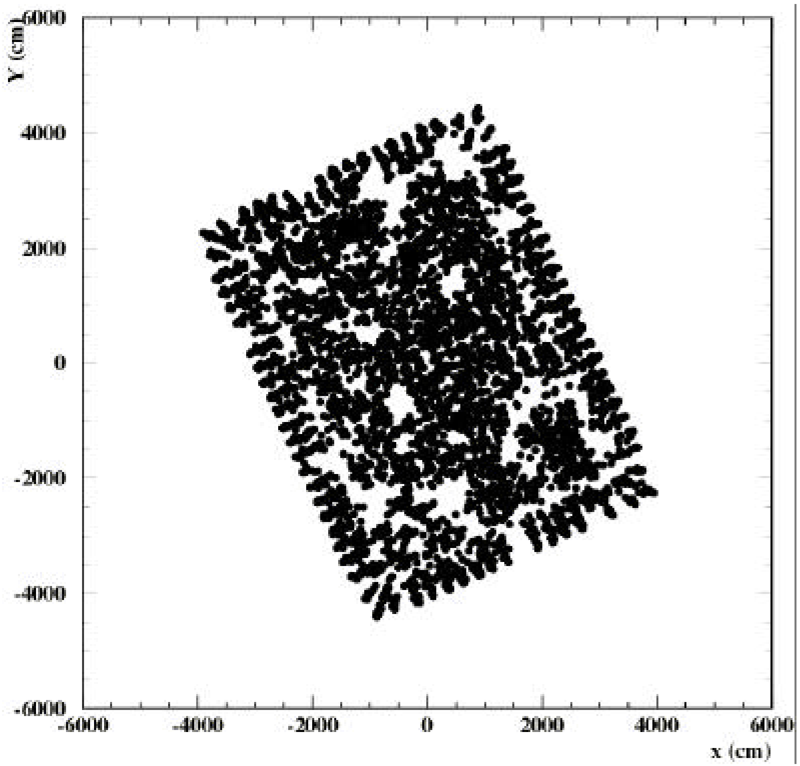

Figure 3 Core positions using old COM core fit

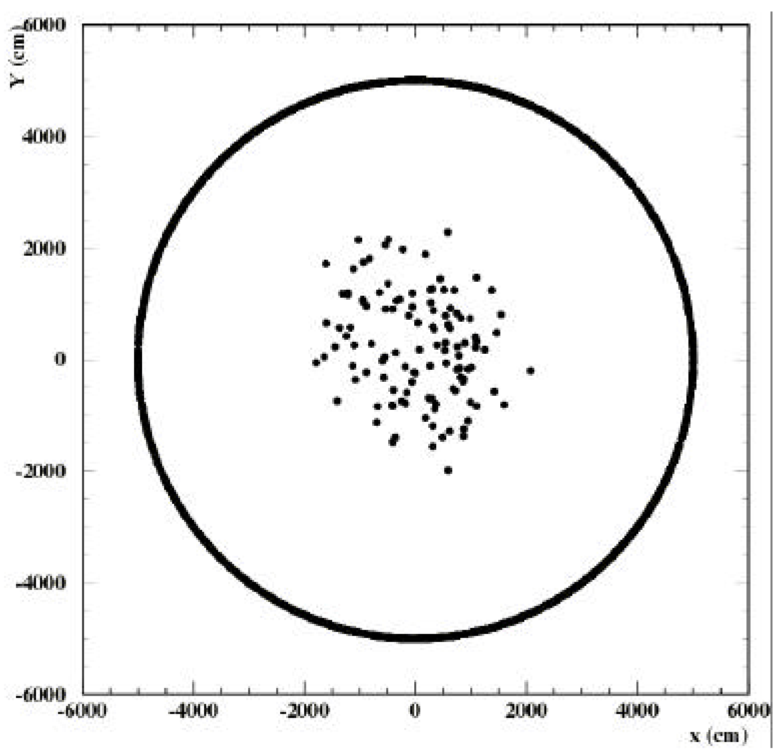

Figure 4 Core positions from This fitter. Note the large number of cores off pond at the fixed radius of 50 meters.

Performance

The performance of the new core fitter was checked using gamma-ray Monte Carlo events with a spectral index of –2.4. Figure 5 shows the angular difference between the true core position and the fit core position on the X-Y plane. This shows how accurately the "direction" of the core, relative to the pond, is determined. The fitter does fairly well, given there is no information outside the pond, with most cores fit within 35 degrees of the true core. The distribution of the difference between the reconstructed shower direction and the true shower direction is compared for the old COM cores and this core fitter in Figure 6. This core fitter does somewhat better on average of reconstructing the true shower direction.

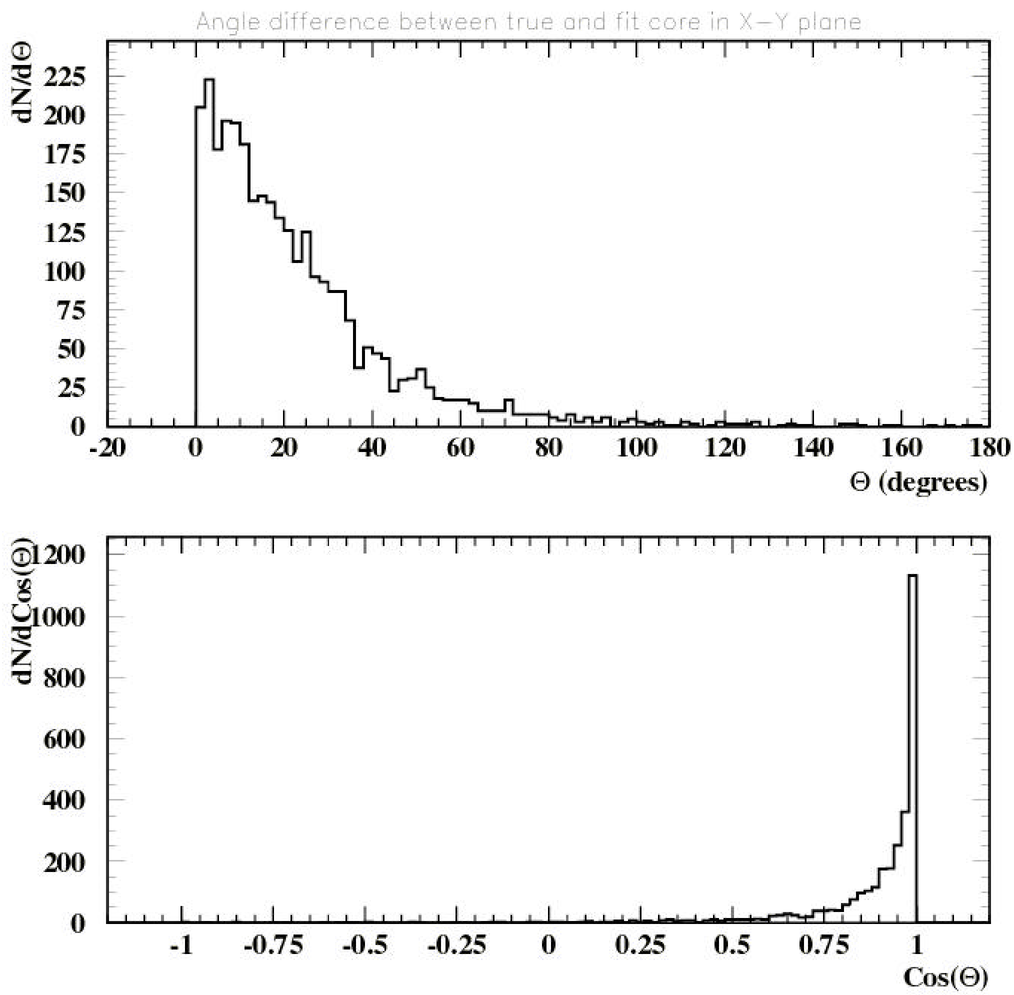

Figure 5 Angle difference between true and fit core direction. Top plot shows distribution of angle difference. Bottom plot shows the cosine(ang-diff) distribution.

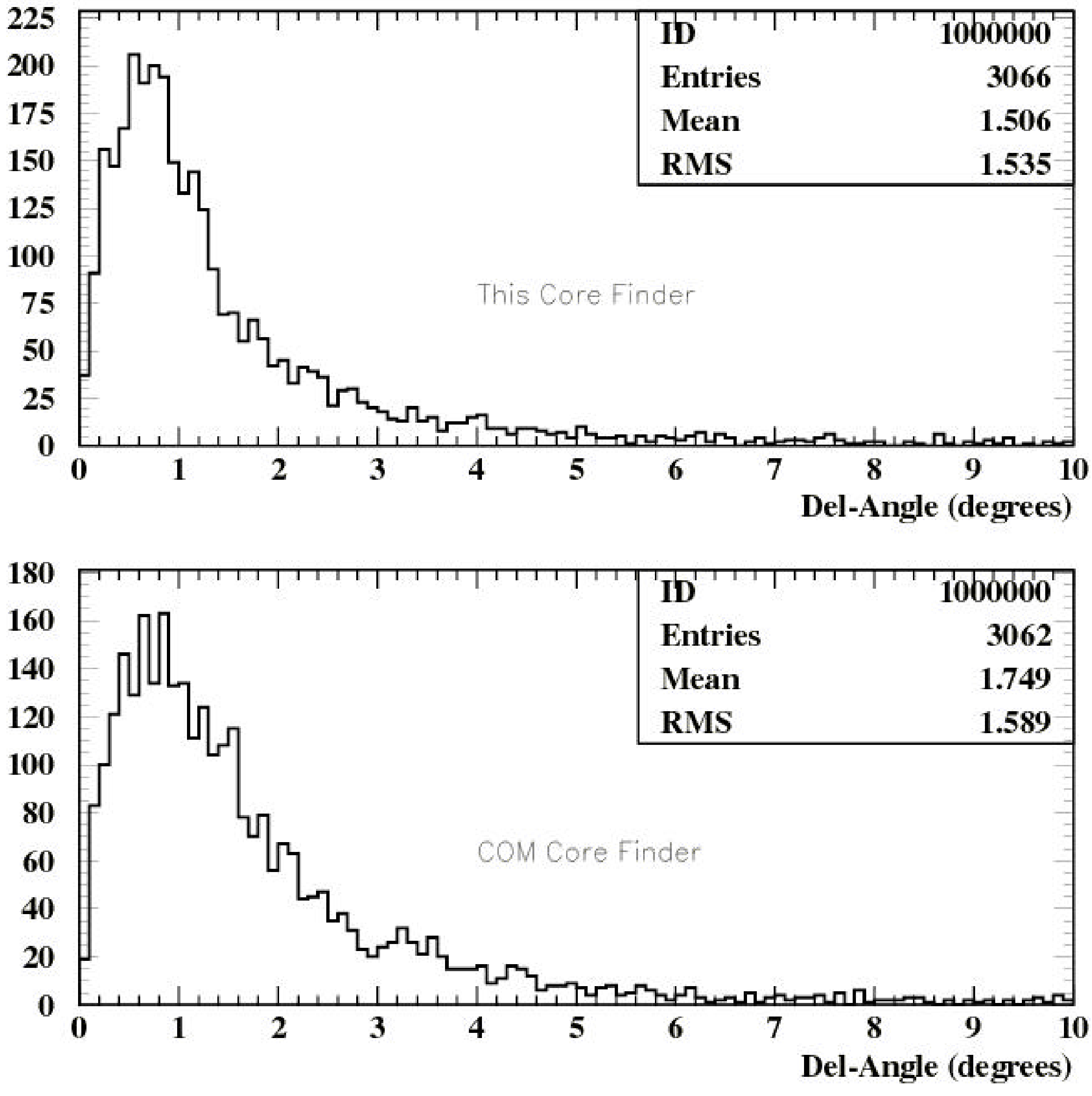

Figure 6. Del-Angle distribution for the this fitter (top) and the COM fitter (bottom).

Finally, to evaluate the actual increase in sensitivity we expect from the improved angular reconstruction with the core finder, we calculate the expected sensitivity to the Crab. To do this we use the gamma Monte Carlo to determine angular bin size that gives us the largest signal to square-root bin area for three cases of core position:

1. True core position
2. This core finder
3. COM core finder

In all three cases the sensitivity is a function of the curvature correction. Figure 7 shows the results. The improvement in sensitivity using this core finder is ~30%. The maximum improvement if we new the true core position (with outriggers for example) is ~60-70%. Also note from the figure that as we get more accurate at finding the true core position, the optimal curvature correction increases toward the higher actual value of the shower front curvature.

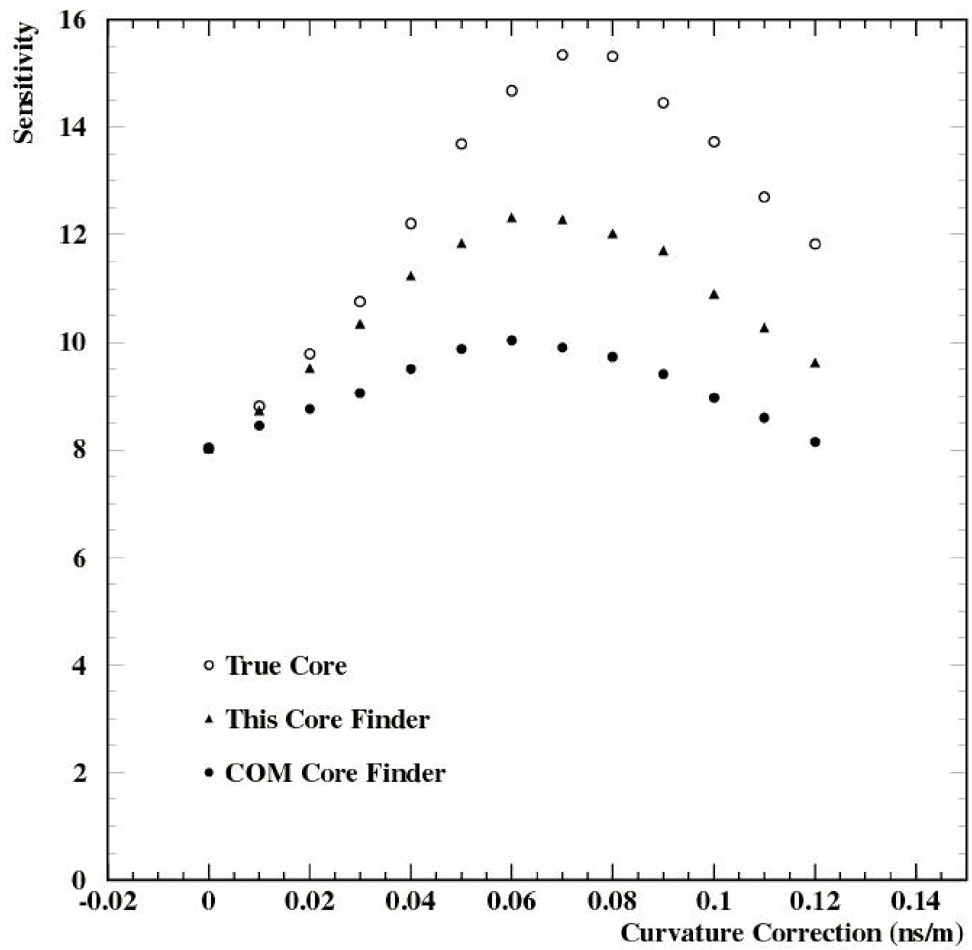

Figure 7. The relative sensitivity to the Crab versus curvature correction.

Summary

We have described a new core finder that improves our expected sensitivity by approximately 30 percent over the present core finder. The maximum improvement we would expect with a perfect core finder is approximately 70 percent. Clearly, the outriggers will eventually give us significant improvement.

The core finder described here can undoubtedly be improved further. We have tried varying the radius at which we place the core outside the pond. The present value of 50 meters is about optimum. This makes sense since the distribution of core distances peaks at around 50 meters. There may be ways to improve this core finder by trying to determine if the core looks far off the pond or nearby the pond, as opposed to just on or off. In addition, only the air shower tubes have used here. It may be possible to make improvements using the muon layer tubes as well.