Measuring the Energy Spectrum of a Source with Milagro

I present a fast and simple way for Milagro to measure the energy spectrum of a source of VHE gamma rays. In this approach the source is assumed to have to cut-off, but to be described by a simple power law in energy. The method depends on the energy dependence of the compactness cut and the fact that by making hard cuts in compactness the background rate drops quickly enough so that we can still measure a significant signal. The method simply measures the Signal to Background ratio as a function of the compactness cut. I show below that this parameter is a good measure of the source spectral index.

The Simulation and Event Reconstruction

I have used the "standard" set of GEANT3 simulation files (air between water and cover, no water on the cover, baffles on all PMTs), the VME trigger, and Tony's reconstruction (with outriggers) for all of the plots shown below.

The Energy Dependence of Compactness

It was shown in the Crab paper (and a previous memo by myself) that the gamma-ray efficiency of the compactness parameter is a strong function of the gamma-ray energy. This fact, coupled with the excellent background rejection of compactness as large values of compactness allow us to measure the energy spectrum of simple power-law gamma-ray sources. In Figure 1 I show the Signal fraction retained as a function of compactness for six different source spectra, E^{-2}, $E^{-2.4}$, $E^{-2.6}$, and $E^{-2.8}$, in 0.2 increments (top to bottom). These plots have been normalized to 1 at a compactness of zero. So the differences are independent of the fact that we measure a stronger signal from a harder source. In Figure 2 I show the same plot for the proton background. After a compactness of 6 no Monte Carlo data survives and I have simply flattened the proton spectrum at the value of C=6 for larger values.

In Figure 3 I show the Signal to Background ratio as a function of compactness cut. The y-axis is in arbitrary units.

It is clear from these plots that the dependence of the S/B vs. compactness cut can in principle be used to measure the energy spectrum of a source of gamma rays. Before concluding that principle and reality are the same we need to put error bars on the curves and insert a realistic signal to background level for Milagro.

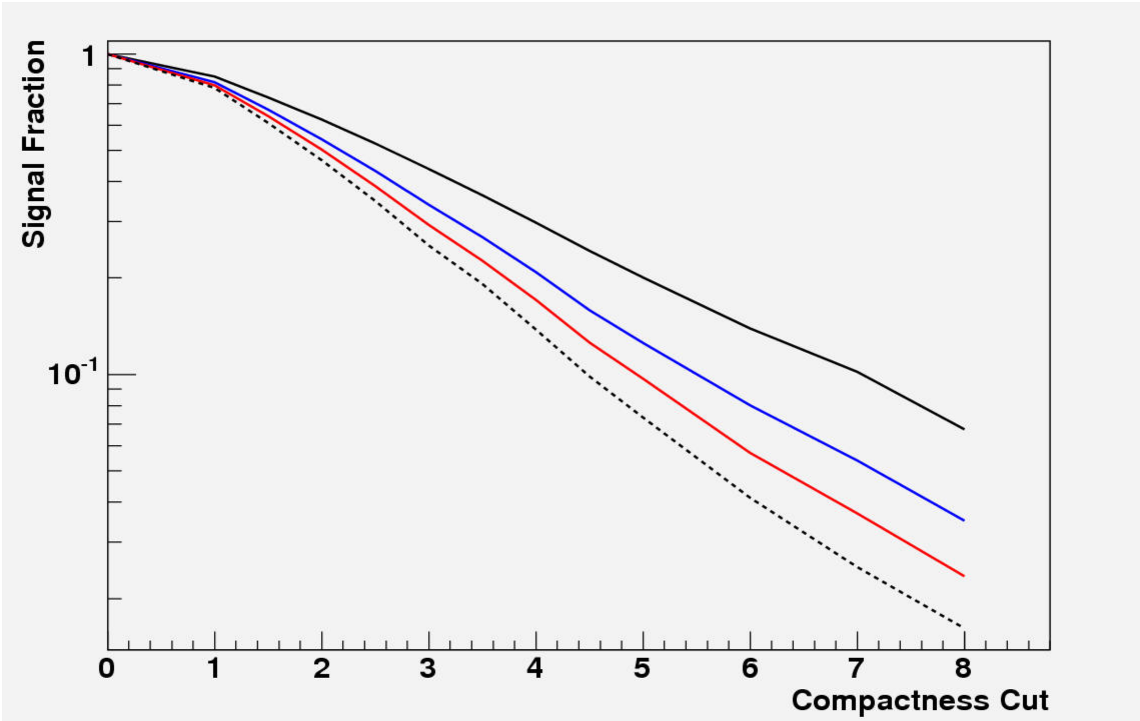

Figure 1 Signal Fraction vs. Compactness Cut for four different source spectra E^{-2}, $E^{-2.4}$, $E^{-2.6}$, $E^{-2.8}$ (top to bottom)

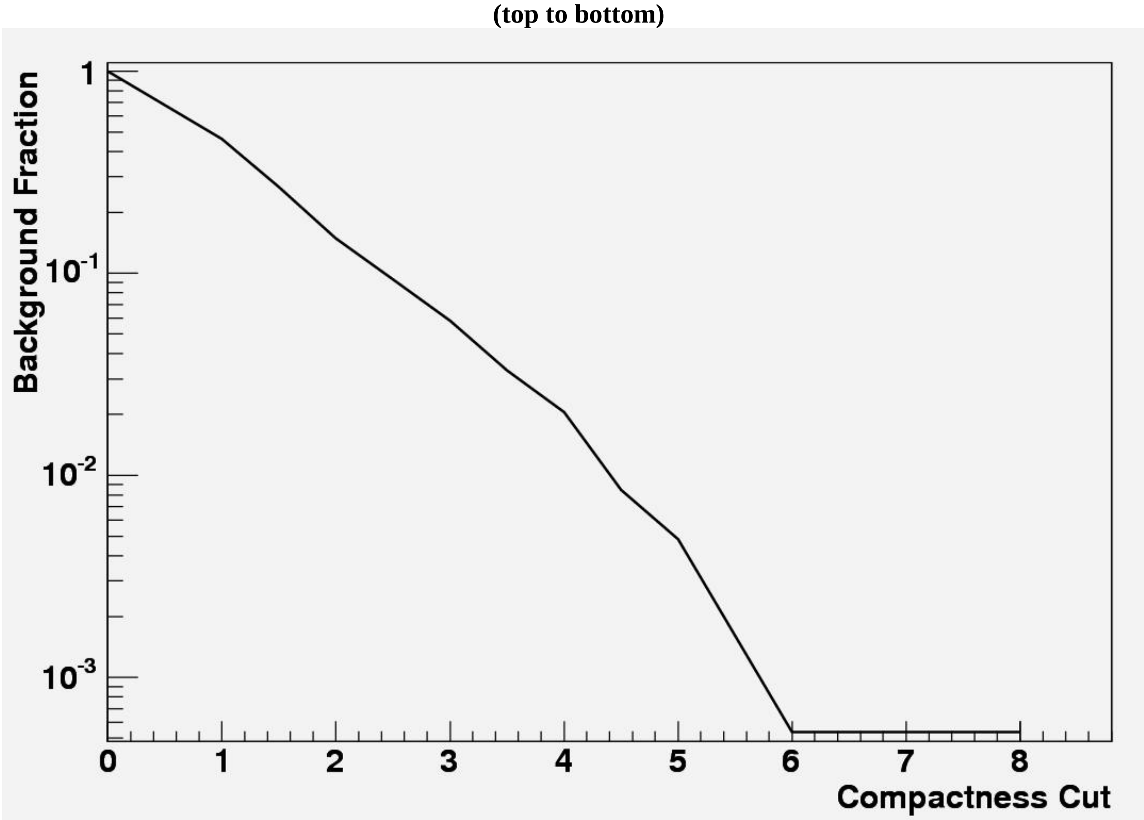

Figure 2 Proton Fraction as a function of compactness cut. Beyond C=6.0 no proton events survived (in the Monte Carlo) and the fraction at 6.0 is used.

Simulation of a Realistic Signal

Since our default analysis is performed with a compactness cut of 2.5 I renormalized all of the above curves to yield the equivalent significance at C=2.5. The data rate was taken from the Crab paper to be 20,000 background events/day with no compactness cut. The number of signal events were given by the simulation of a Crab transit and renormalized to give the desired significance at C=2.5. Below I show the results for several different values of the significance (5σ, 7.5σ, 10σ, and 16σ). These results are shown in Figures 4-7. To better demonstrate the effect I have only plotted the results for C>2.5. This region is the critical region where the curves diverge beyond the error bars. The errors are taken to be sqrt(S+B)/B for each data point. Obviously as the significance of our signal increases the resolution of the method increases, but to my surprise even with a mere 5σ signal we seem to have a resolution in spectral index of roughly 0.2. Also note that the resolution degrades as the source spectrum steepens. So that with only a 5-sigma signal we can differentiate between an $E^{-2.0}$ and an $E^{-2.2}$ source we need a ~7-sigma signal to differentiate between an $E^{-2.6}$ and $E^{-2.8}$ source.

Conclusions and Future Work

Surprisingly, Milagro can measure the source spectrum even with a somewhat marginal signal (to the extent that we trust the MC simulation of compactness), if the source can be represented by a simple power-law. The compactness distribution should be compared for data at high values of C and the technique should be applied to the Crab to verify that it works. Further work could also include sources with cutoffs or IR absorbed high-energy spectra to see if they may also be distinguishable from the simple source model presented here.

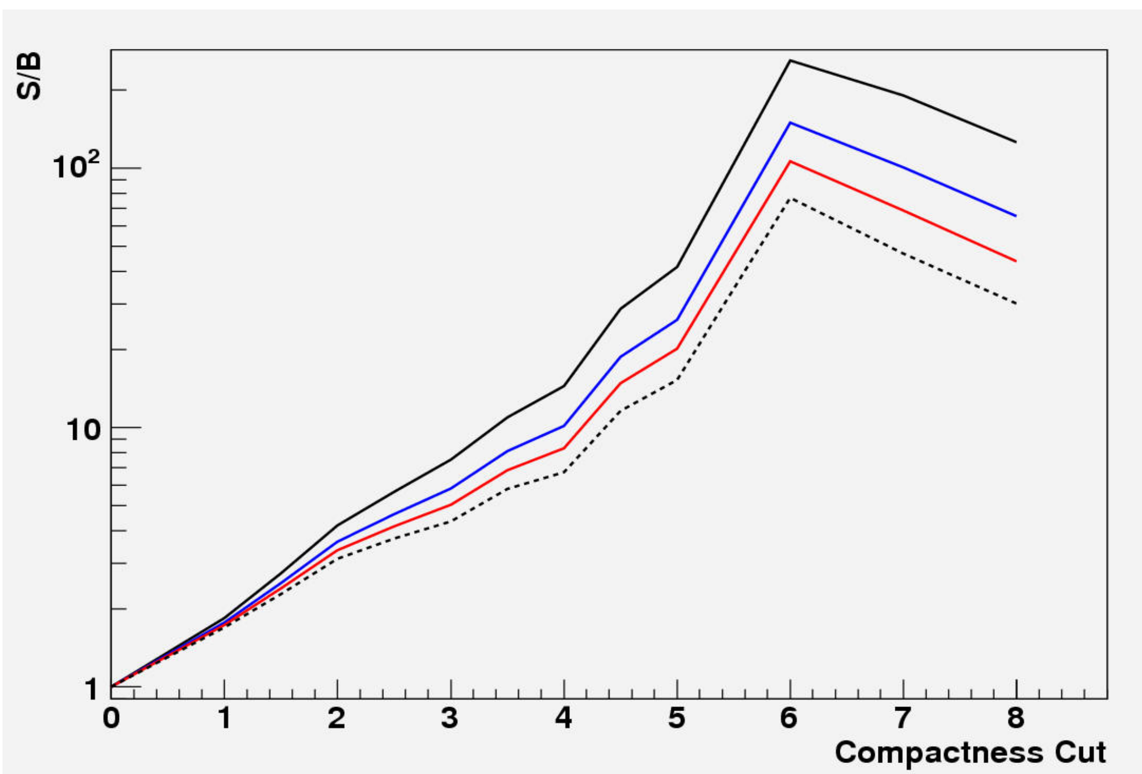

Figure 3 Signal to Background Ratio vs. Compactness (arbitrary units on the y-axis).

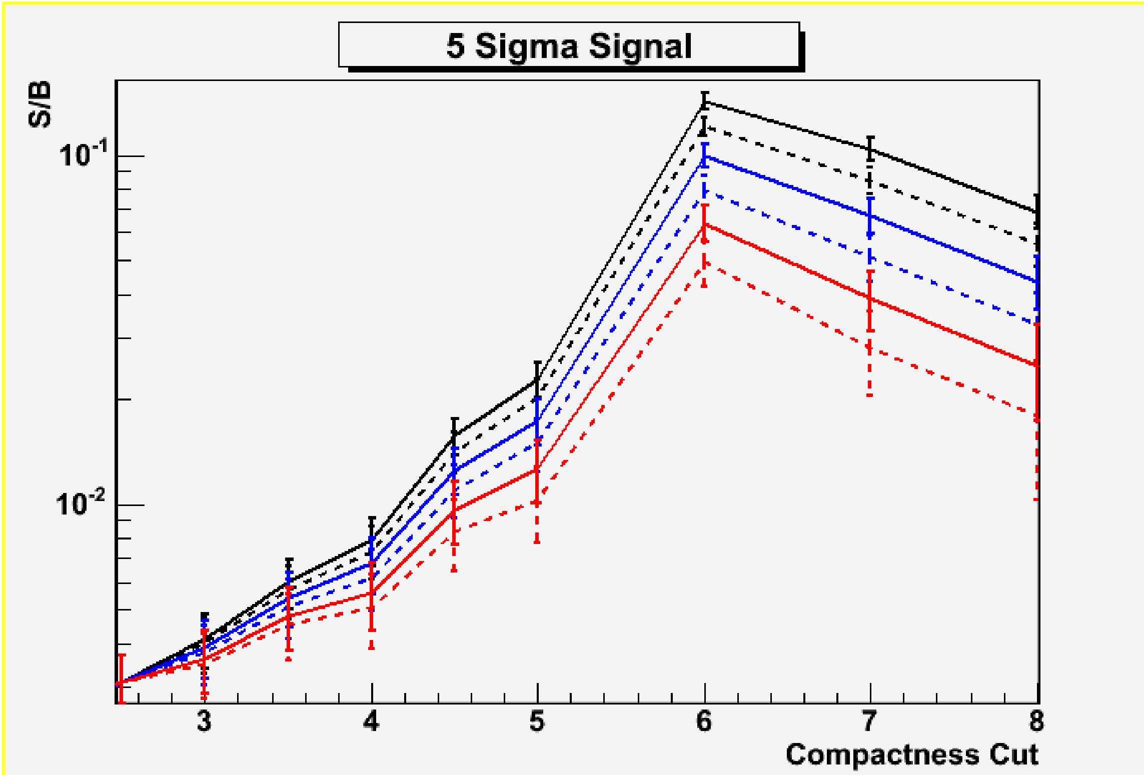

Figure 4 S/B ratio for a 5-sigma signal (at C=2.5)

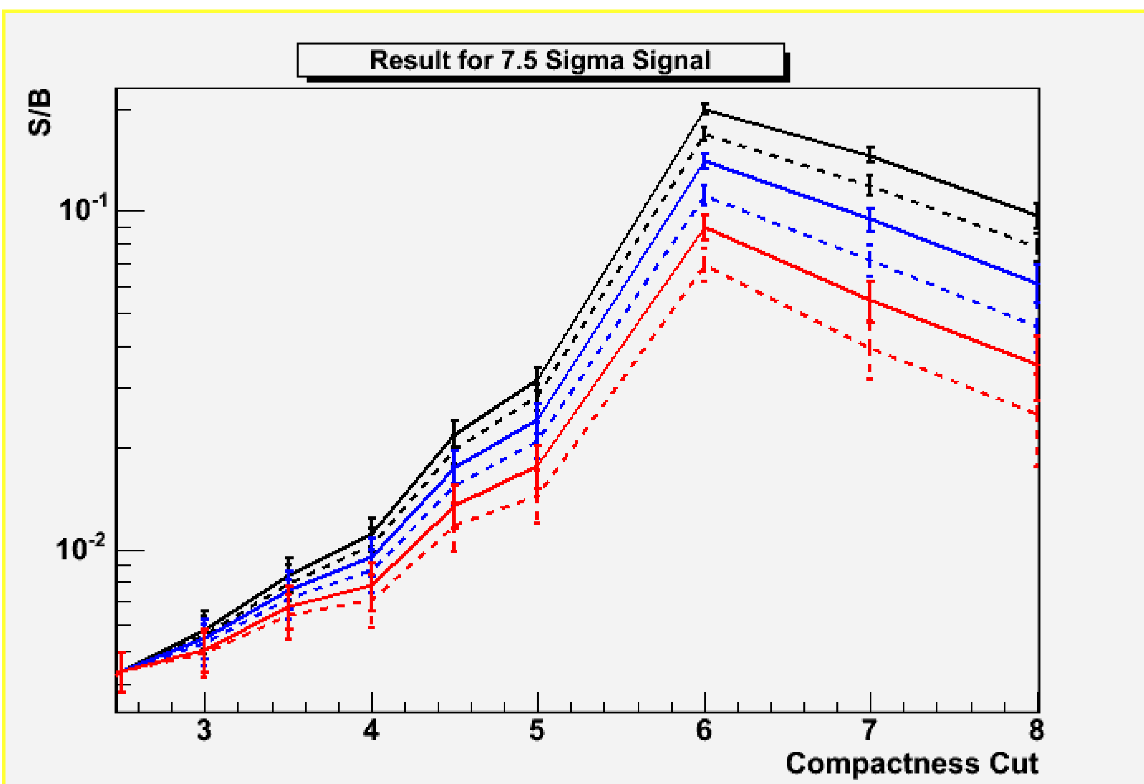

Figure 5 S/B ratio for a 7.5-sigma signal (at C=2.5)

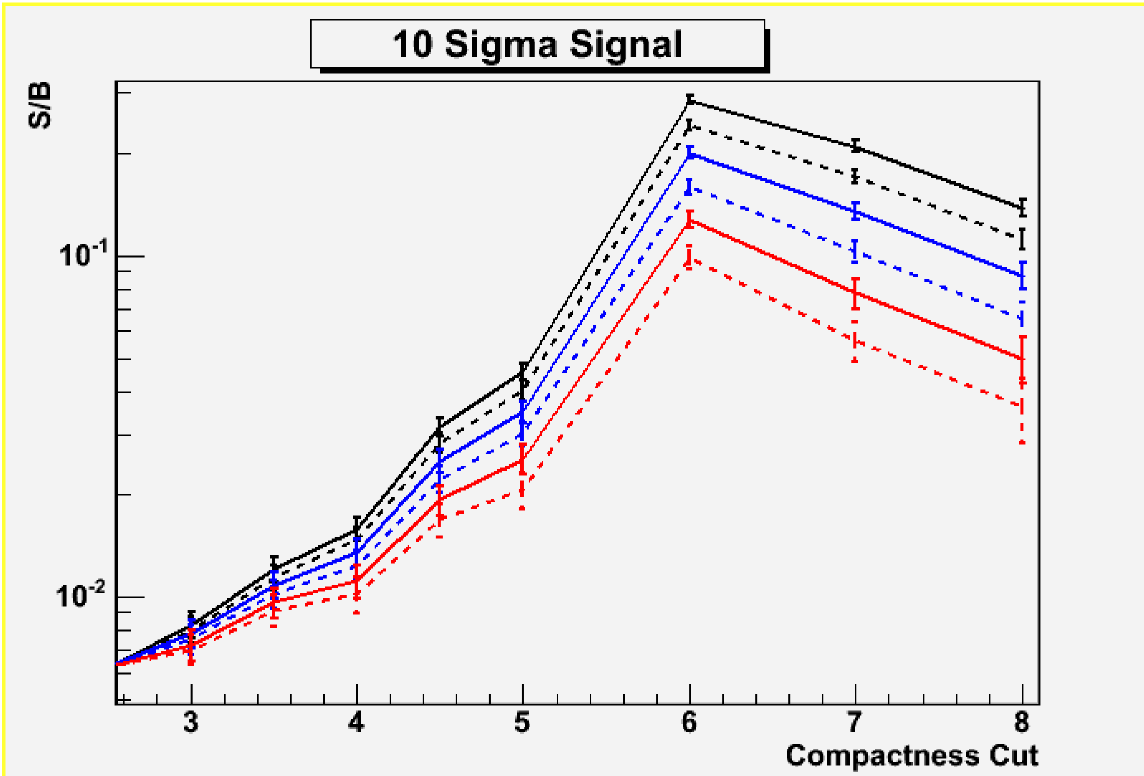

Figure 6 S/B ratio for a 10-sigma signal (at C=2.5)

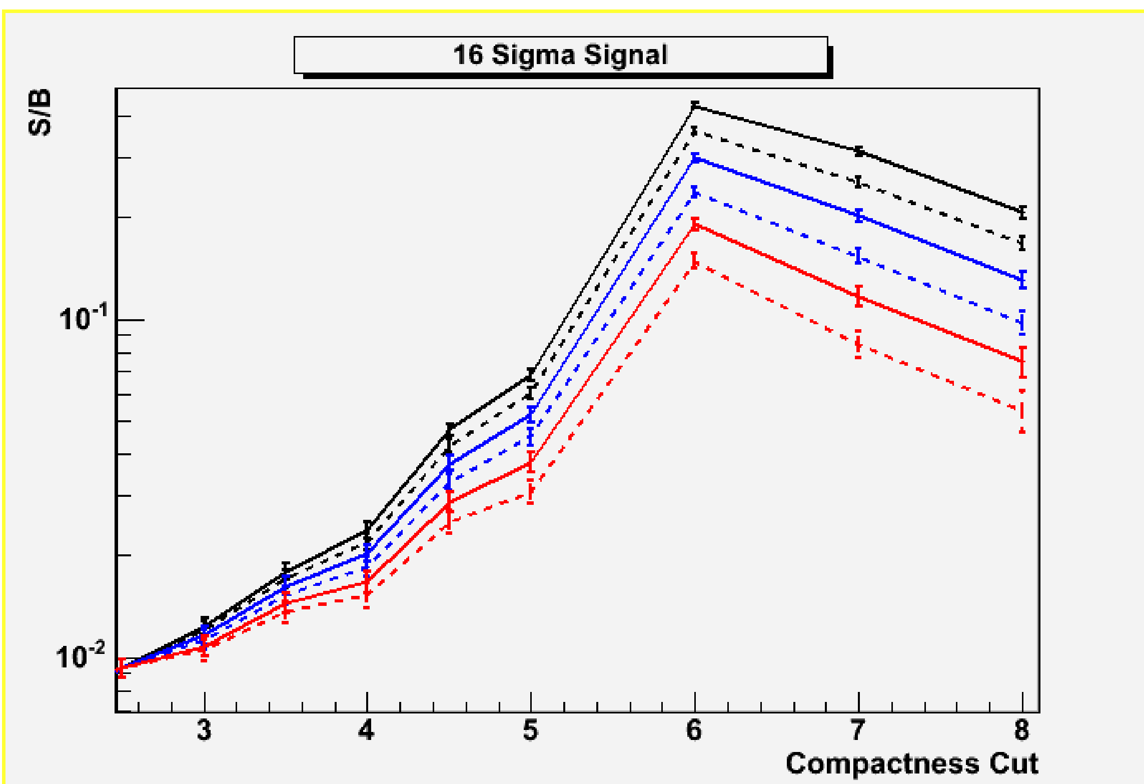

Figure 7 S/B ratio for a 16-sigma signal (at C=2.5)