Compactness for Sources with Non-Crablike Spectra

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Abstract

The compactness cut was optimized for sources with a Crab-like energy spectrum, yet as demonstrated in the Crab paper (Atkins, 2003) compactness is energy dependent for gamma ray induced air showers. Therefore it is natural to expect the optimal compactness cut to be dependent upon the energy spectrum of gamma rays (at the top of the atmosphere) from a given source. In this memo I investigate several different cases. First the case of a source with a known energy spectrum such as Mrk 421 and second for gamma ray bursts at different redshifts. I find that indeed the compactness cut should be changed for different source spectra and GRB distances. For Mrk421 ($E^{-3.0}$ spectrum, Aharonian 1999 & 2001) the optimal cut is C>1.6 which results in a Q-factor of 1.4 with a gamma-ray efficiency of 65%. For GRBs the cut depends upon the redshift and also the trigger (risetime or multiplicity), but in general a cut of C>~1 is optimal and the Q-factor lies in the range of 1.1-1.2. While this gain is minimal, I think one can still utilize compactness in the GRB analysis to help differentiate between background fluctuations and true signals.

Data Set Description

I am using version 3.2 of the Monte Carlo generated events. The gamma ray events are generated from 100 GeV to 10 TeV and the proton events from 50 GeV to 10 TeV. The events are weighted by core distance since they were generated with a flat radial distribution. The reconstruction used is the new improved reconstruction from Tony Shoup and I use the Milinda code to reconstruct the Monte Carlo data. For the Mrk 421 analysis I used a simple 55 PMT multiplicity trigger appropriate for the bulk of the REC data residing on disk and for the GRB analysis I used both the multiplicity trigger and the rise time trigger. The rise time trigger was simulated as the current settings on the VME trigger card: (nTop>75 && tRise<INF) OR (nTop>52 && tRise<87.5ns) OR (nTop>23 && tRise<50ns) OR (nTop>23 && tRise<INF, prescaled by 1000). Table 1 gives the analysis cuts used, constructed to mimic the actual analysis. The cuts for the GRB analysis are those currently used by David Noyes.

Table 1 Triggers and analyses cuts used in this memo.

Analysis	Trigger	nFit	dAngle
Mrk 421	nTop>55	20	1.2 degrees
GRB	nTop>55 and risetime	5	1.7 degrees

Compactness and Gamma Ray Energy

Figure 5 of Atkins 2003 shows the energy dependence of compactness for gamma-ray induced events. It is reproduced as Figure 1 below for completeness. At 100 GeV the gamma-ray efficiency of C>2.5 is only ~0.2, while at high energies (>10 TeV) it rises to ~0.7. This energy dependence indicates that one would want to adjust the compactness criteria for sources with different spectra. (In this memo source spectrum refers to the spectrum at the top of the atmosphere.)

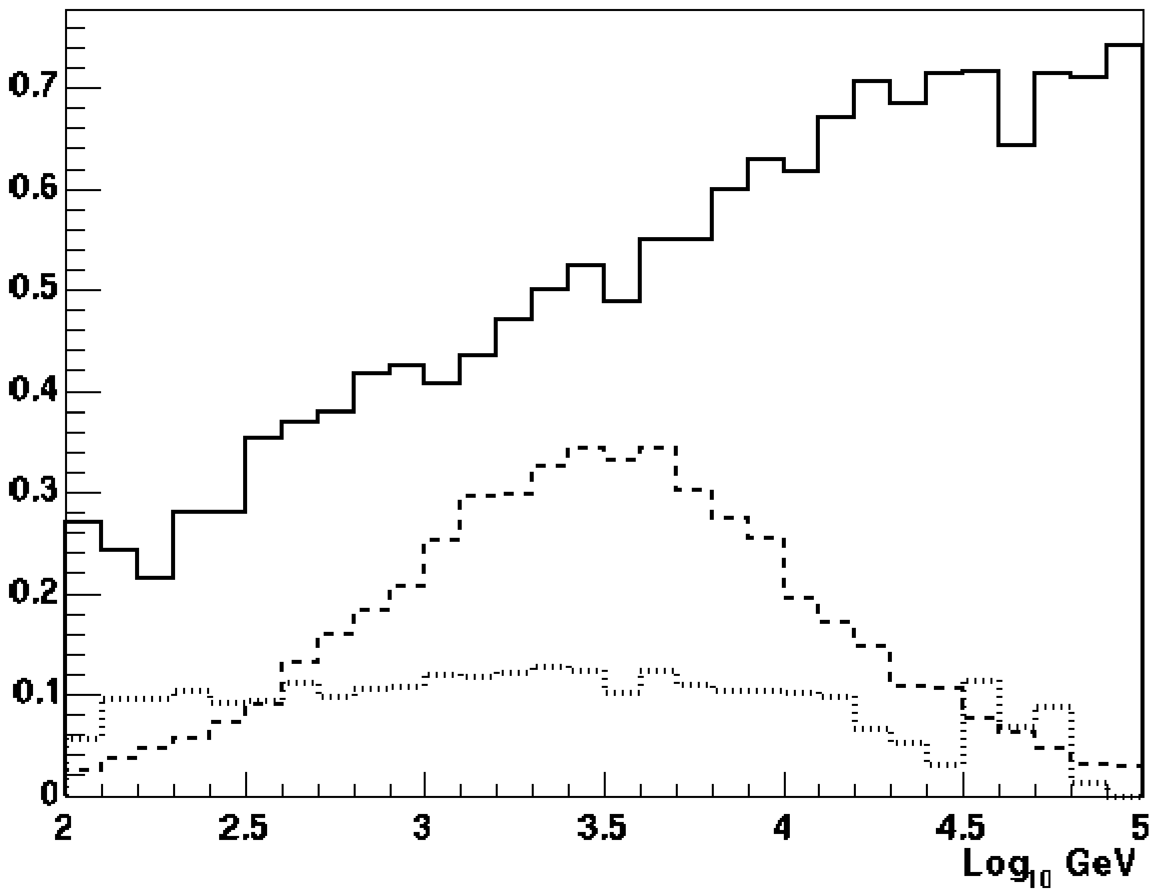

Figure 1 The solid line shows the efficiency of the requirement C>2.5 for gamma-ray induced air showers. The dotted line shows the same for proton induced air showers and the dashed line shows the energy response of Milagro.

Mrk 421

The spectrum of Mrk 421 has been measured by the HEGRA telescope in the energy range of interest to Milagro (>1 TeV). They find a rather steep spectrum of E^{-3}, with no evidence of curvature between 500 GeV and 7 TeV. In Figure 2 I show the compactness distribution for protons, gamma rays with an $E^{-2.49}$ spectrum, gamma rays with an $E^{-3.0}$ spectrum and for gamma rays with an $E^{-2.0}$ spectrum. Figure 3 shows the efficiency as a function of the compactness cut for each of these spectra and Figure 4 shows the quality factor as a function of compactness criteria for each of these spectra. Between *C* values of 1.6 and 2.1 the Q factor is essentially constant at a value of 1.4, though the gamma-ray efficiency drops (at *C*>1.6 the gamma-ray efficiency is 65%). I believe that all other things being equal it makes sense to maximize the gamma-ray efficiency so recommend a cut of *C*>1.6 for the analysis of any source with an $E^{-3.0}$ spectrum, such as Mrk 421. Note that at our nominal cut of C>2.5 the Q-factor is not much less than 1.4 (~1.3), but the gamma-ray efficiency is only 41% (a 37% decrease). Based on these results I suggest that the daily maps be remade with a looser compactness cut for the Mrk 421 analysis and paper. This analysis should be repeated for the old reconstruction (OFF core fitter) and for the risetime trigger.

Note that for very hard spectra the Q-factor gets quite high (>3) though with a relatively low gamma-ray efficiency of 10%.

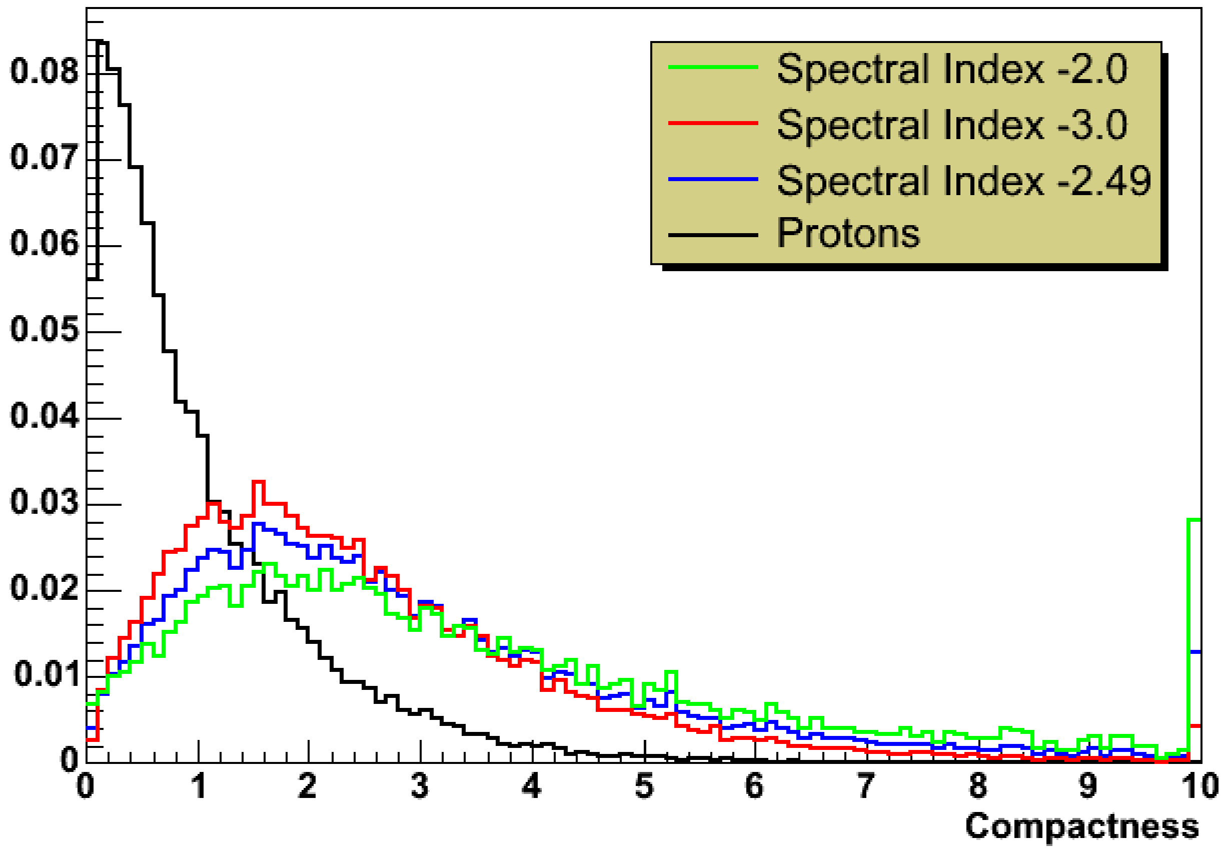

Figure 2 Compactness distributions for protons and gamma rays from sources with 3 different spectra.

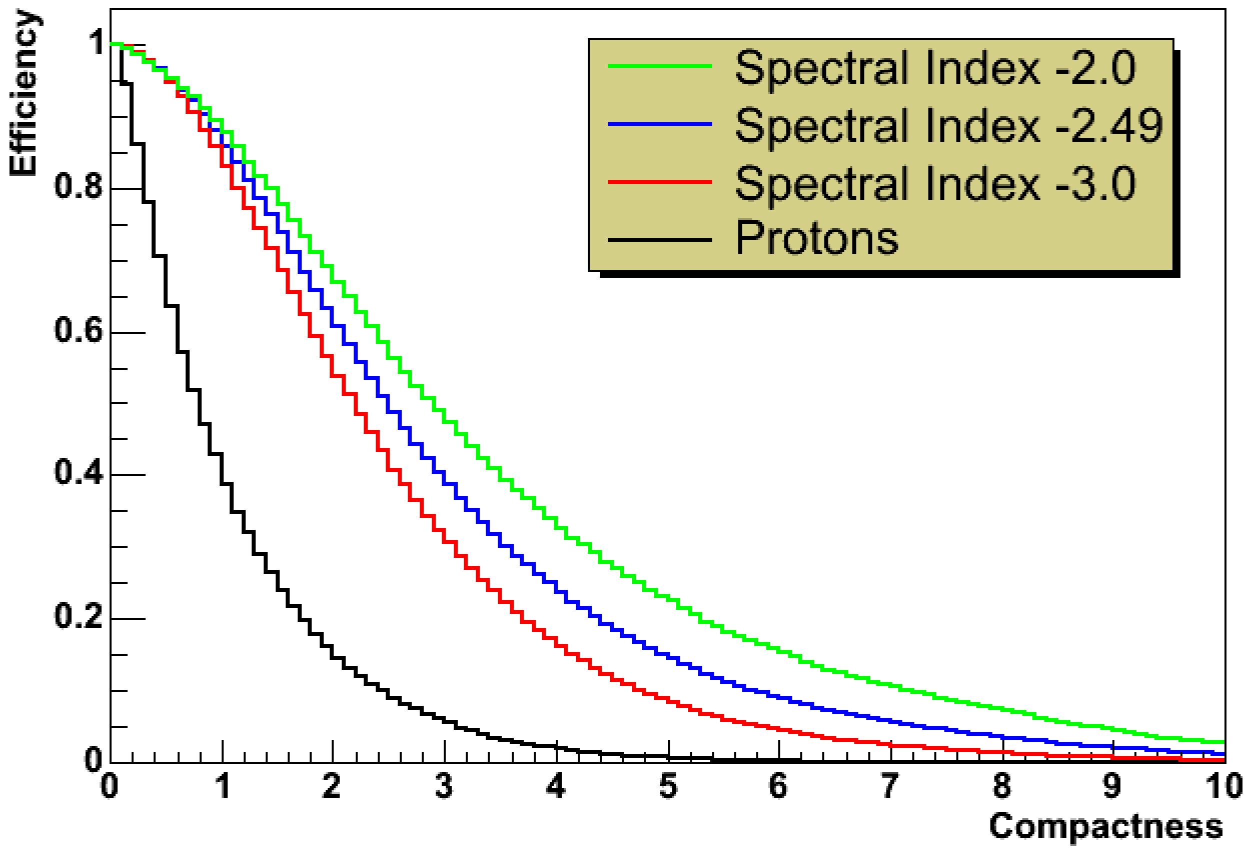

Figure 3 Efficiency as a function of compactness cut for protons and gamma rays with 3 different spectra.

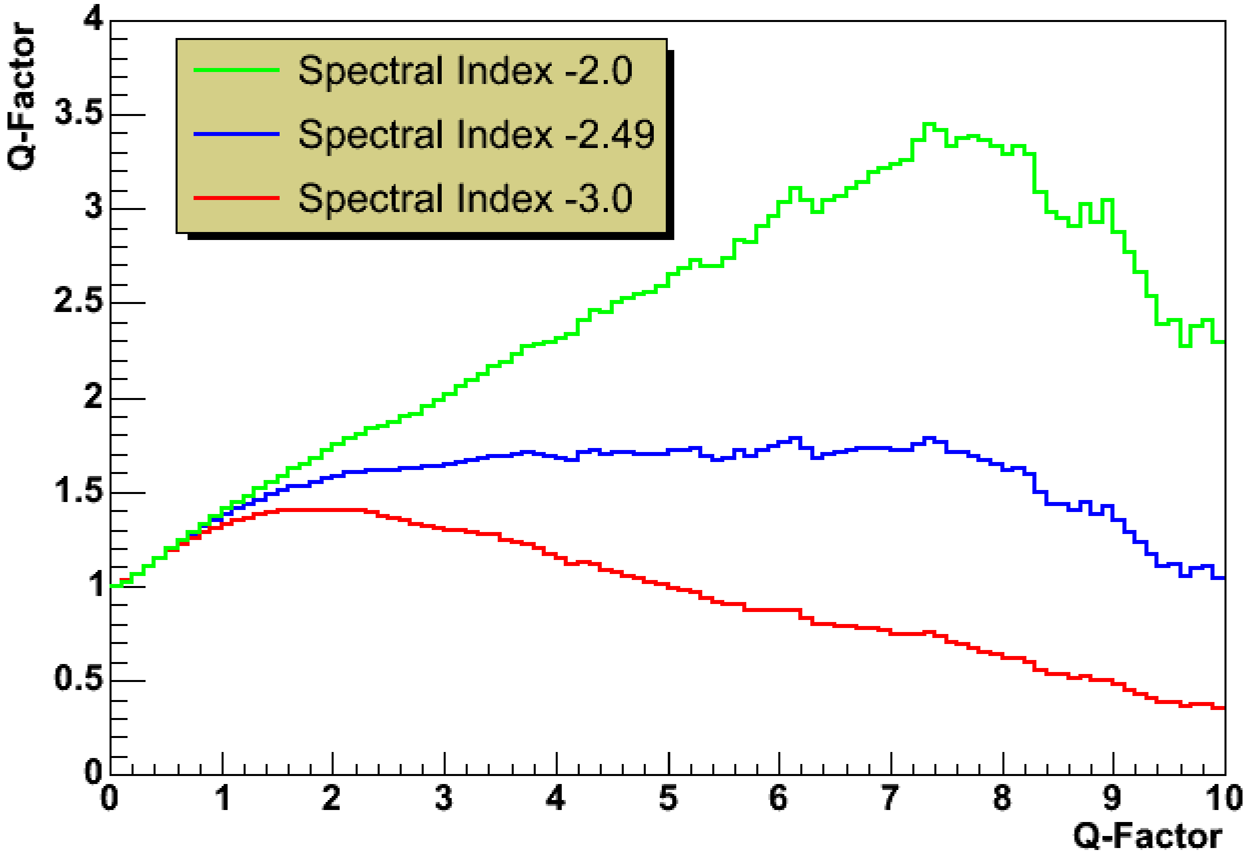

Figure 4 Quality factor as a function compactness cut for gamma rays with 3 different spectra.

Gamma Ray Bursts

While the inherent spectra of GRB are unknown at TeV energies we do know that they are at large redshifts. The absorption by the EBL tends to make all the GRB spectra look similar regardless of the inherent spectrum (as long as the intrinsic spectrum is relatively hard). For the work in this memo I have used an E-2.4 intrinsic spectrum and propagated the photons through an EBL as described by De Jager and Stecker as the "Fast Evolution" model (Stecker and De Jager and Stecker 2002). This model gives a larger amount of absorption than their "Baseline" model, but slightly less absorption than the model of Primack (Primack 2000). I have simulated sources at redshifts of 0.1, 0.2, 0.3, and 0.4. Figures 5-8 show the results for the 55 PMT multiplicity trigger. Table 2 summarizes these results. Unlike Crab-like sources the Q-factor drops quickly beyond the optimal value of the compactness cut.

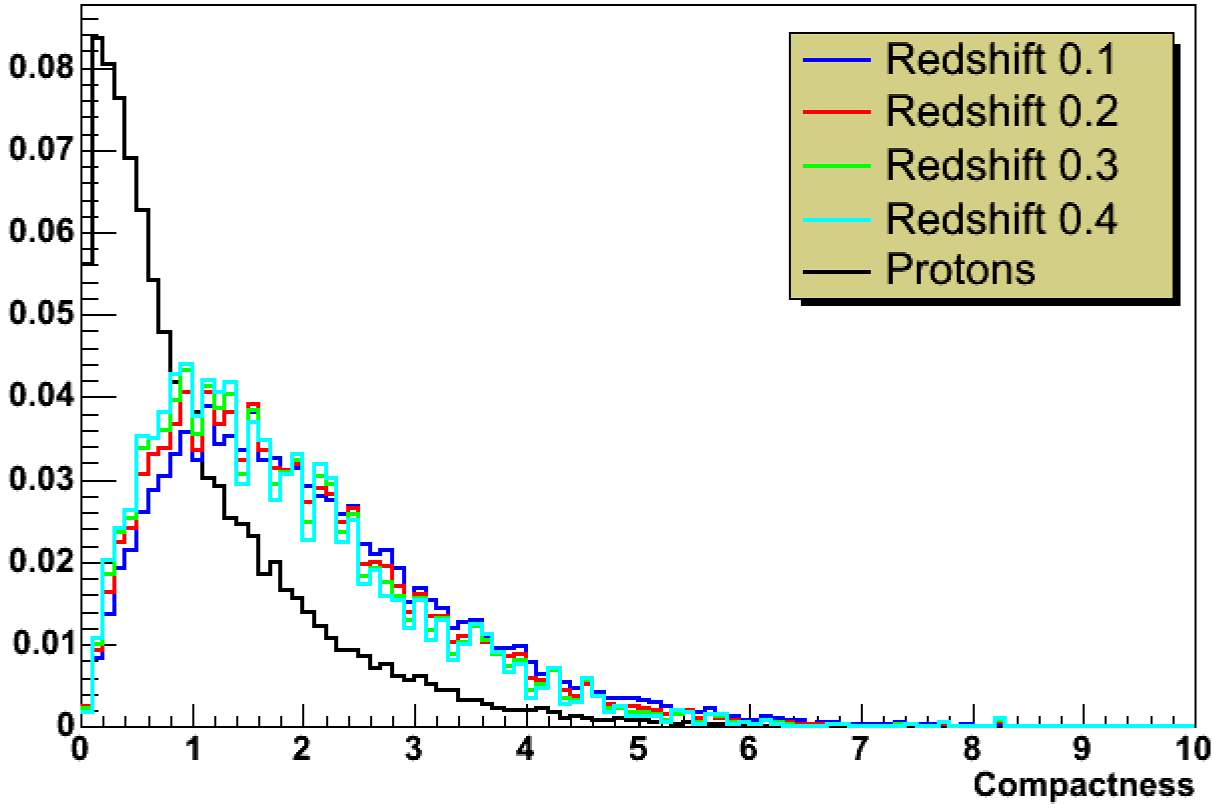

Figure 5 Compactness distribution for a source with a differential spectral index of -2.4 located at 4 different redshifts. See text for EBL model. The trigger requirement was 55 PMTs in the top layer.

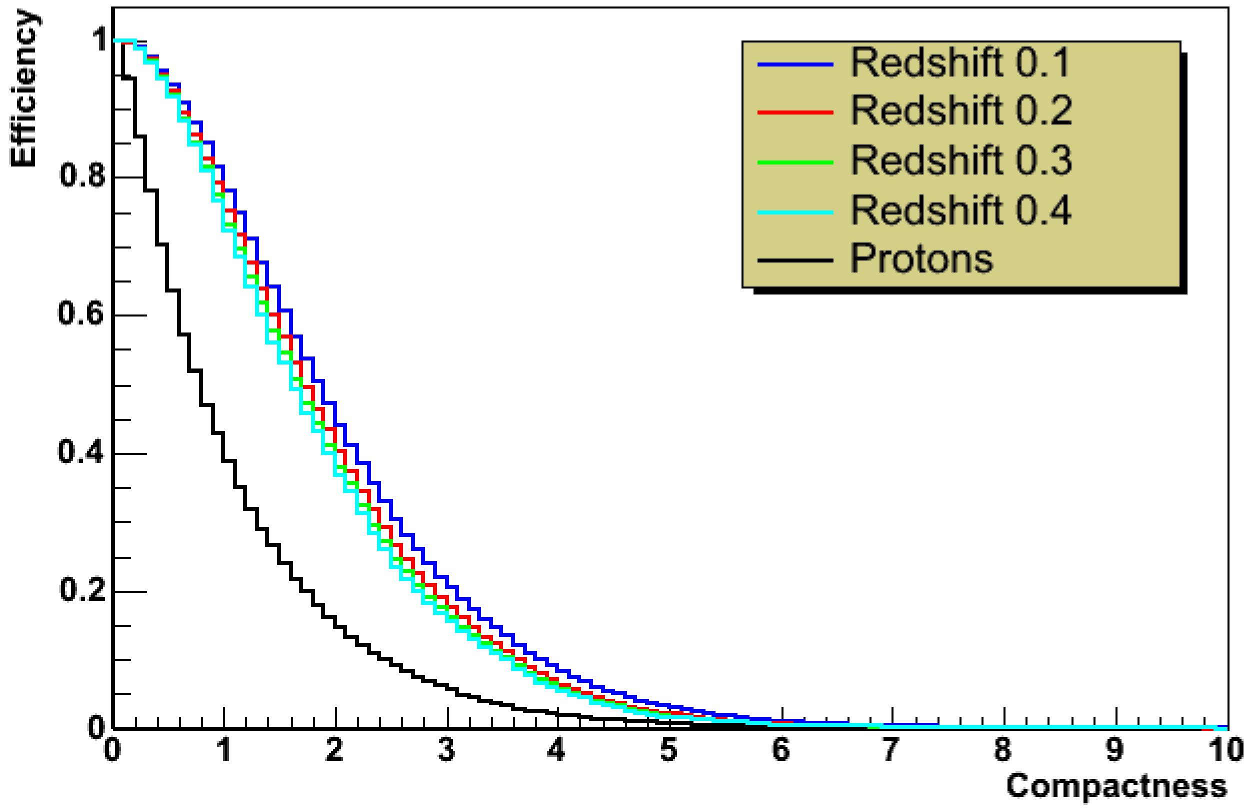

Figure 6 Efficiency as a function of compactness cut for protons and gamma ray sources at 4 different redshifts. The trigger requirement was 55 PMTs in the top layer.

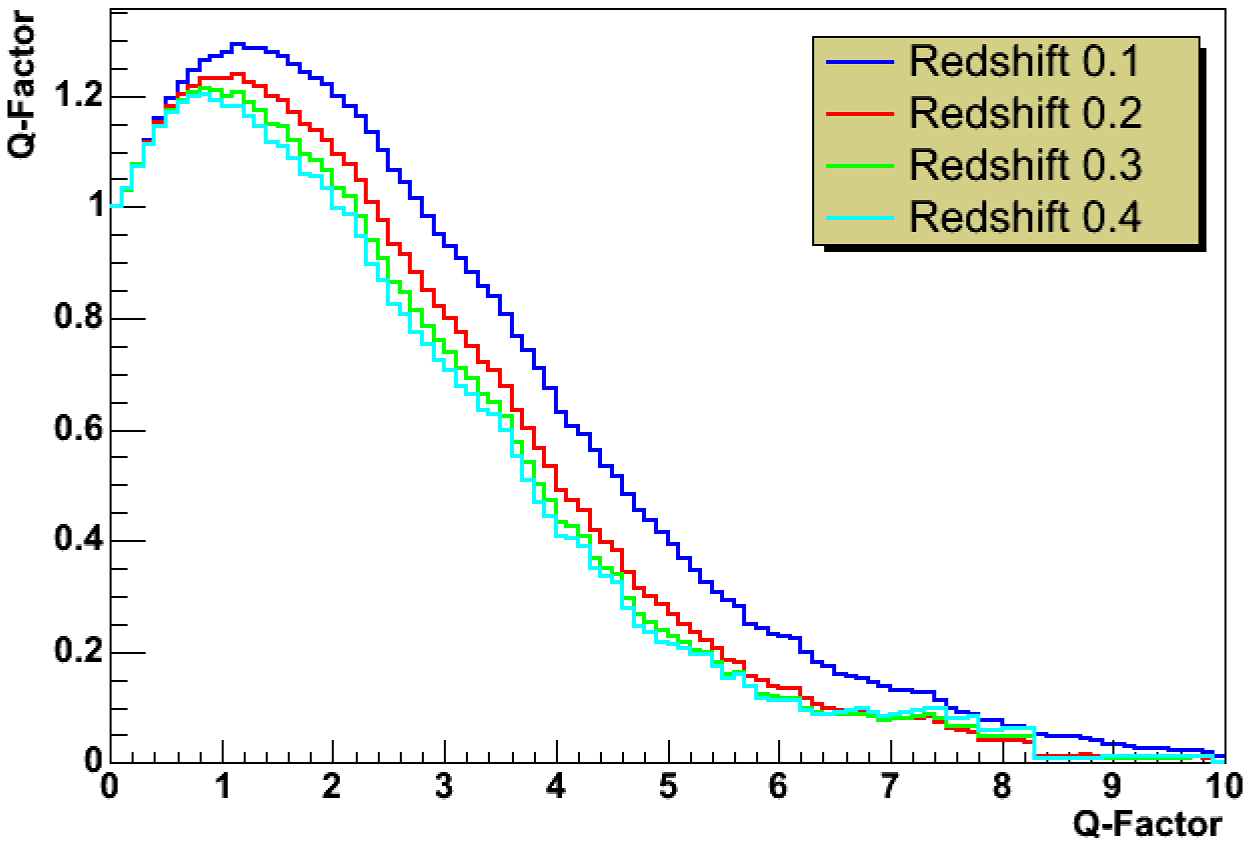

Figure 7 Q-factor as a function of compactness requirement for gamma-ray sources at 4 different redshifts. The trigger requirement was 55 PMTs in the top layer.

Table 2 Summary of compactness requirement, Q-factor, and gamma-ray efficiency for GRBs at 4 different redshifts. This analysis used a multiplicity trigger of nTop>55 PMTs.

	z=0.1	z=0.2	z=0.3	z=0.4
C requirement	>1.1	>1.0	>0.8	>0.8
Q factor	1.3	1.25	1.2	1.2
Gamma Efficiency	75%	75%	82%	81%
Proton Efficiency	35%	39%	47%	47%

The same analysis is now repeated using the risetime trigger. Figures 8-10 show the results for this trigger and Table 3 gives the summary information for GRBs using the risetime trigger.

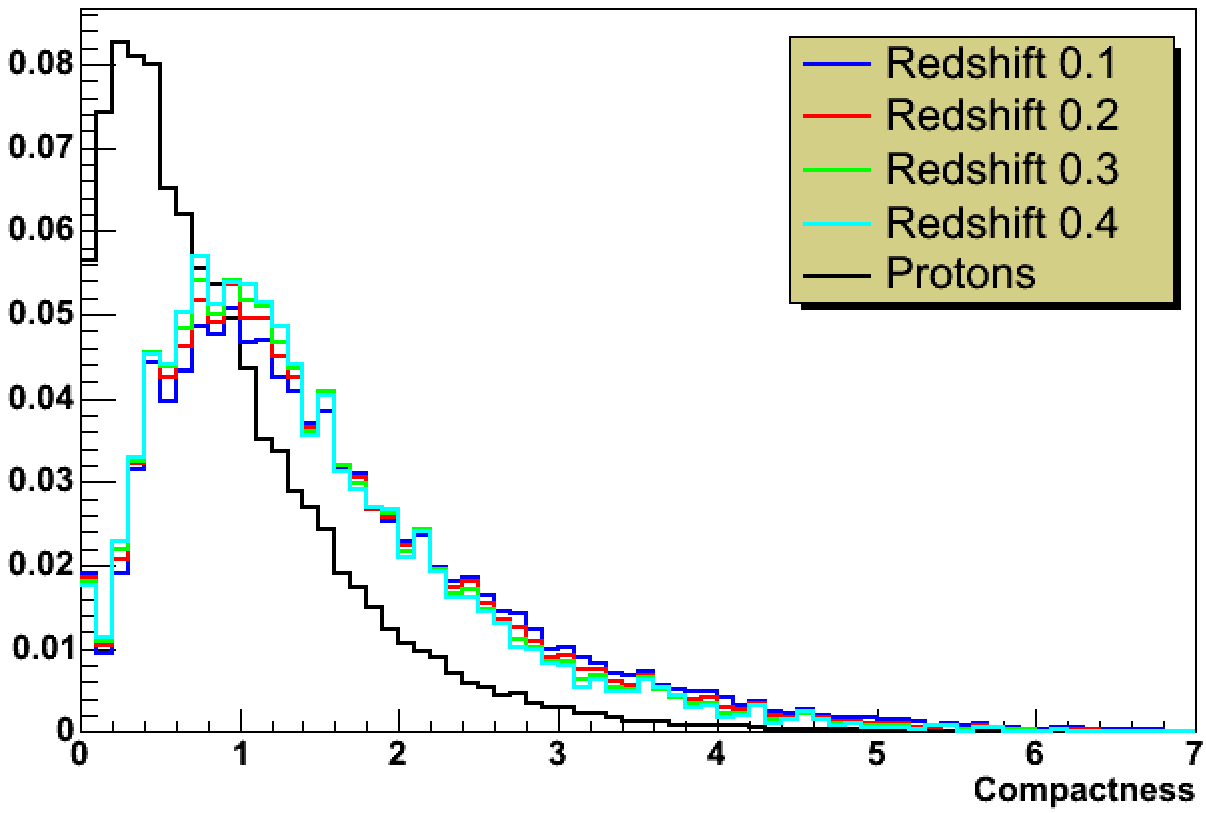

Figure 8 Compactness distribution for a source with a differential spectral index of -2.4 located at 4 different redshifts. See text for EBL model. The trigger requirement was a risetime trigger.

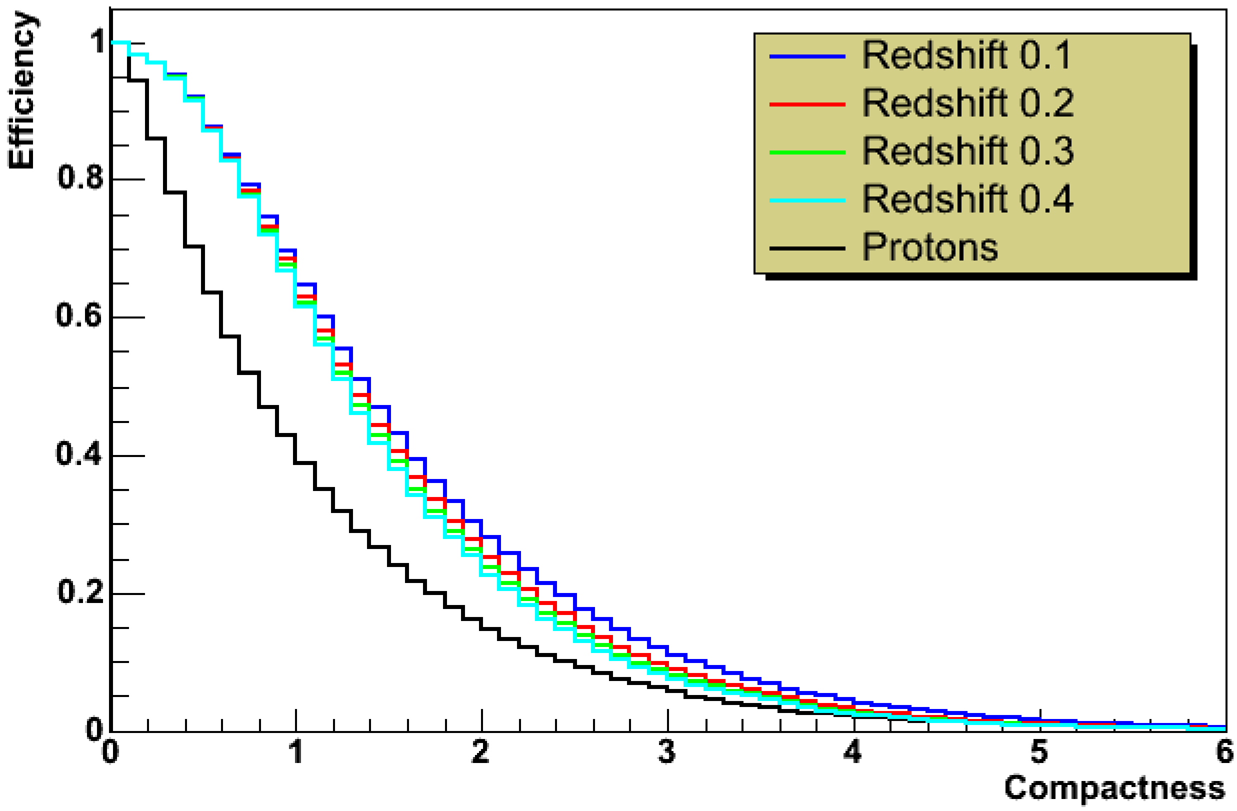

Figure 9 Efficiency as a function of compactness cut for protons and gamma ray sources at 4 different redshifts. The trigger requirement was a risetime trigger.

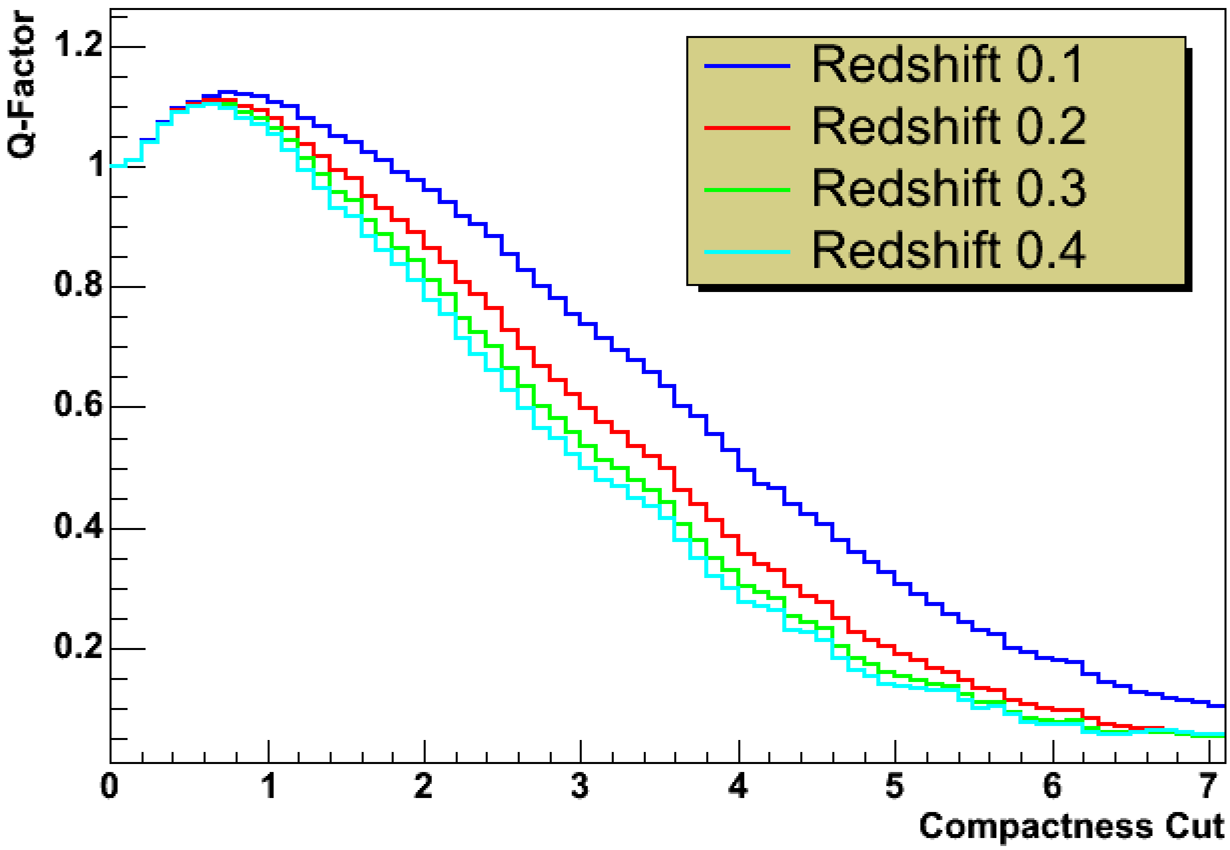

Figure 10 Q-factor as a function of compactness requirement for gamma-ray sources at 4 different redshifts. The trigger requirement was a risetime trigger.

Table 3 Summary of compactness requirement, Q-factor, and gamma-ray efficiency for GRBs at 4 different redshifts. This analysis used a risetime trigger.

	z=0.1	z=0.2	z=0.3	z=0.4
C requirement	>0.7	>0.7	>0.6	>0.6
Q factor	1.125	1.11	1.105	1.1025
Gamma Efficiency	78%	78%	82%	82%
Proton Efficiency	52%	52%	57%	57%

Conclusions

The energy dependence of the compactness criteria requires one to change the compactness cut for sources with different spectra. As expected, steeper spectra require a looser cut on compactness. Therefore each analysis needs to use the Monte Carlo to tune find the optimal compactness cut for the dataset at hand (trigger requirement) and the reconstruction method used. For Mrk421 I find that a compactness cut of 1.6 is optimal and leads to a Q-factor of 1.4. In examining the effect of compactness on gamma-ray bursts I find that the impact of compactness is minimal, leading to a 10% increase in sensitivity for the new risetime trigger. However, this does not mean that compactness has no value in these analyses. The effect of the compactness cut on a putative GRB can have a different effect on the apparent signal if the signal is due to a fluctuation of the background or if it is due to a real GRB. As an example take a GRB of duration 40 seconds at a zenith angle of 20 degrees. From David N.'s burst page this event would have a background of 63 events and the observation was 124 events. From Table 3 we get a proton efficiency of ~55%, so if the burst was pure background after applying the compactness cut we would expect to see 68 events on a background of 34.6 (the significance would drop from 7.7σ to 5.6σ or 40%), however if the burst was real we would expect to observe 84 events with the same background (the significance would go from 7.7σ to 8.2σ). While the difference between 84 and 68 is not huge, it is about 2 standard deviations. A better technique would be to apply a likelihood analysis to the observed compactness distribution and determine the ratio of gammas to protons in the signal based on the shapes given in Figure 8. This would be identical to the analysis I developed in my previous memo **"A Maximum Likelihood Approach to Background Rejection"** 10/25/2000.

References

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