Systematic Uncertainties in Scaler Analyses

Julie McEnery

1 Introduction

Two important results in Milagrito were obtained by analysing the scaler rates. These were the detection of an excess in the high threshold scalers during a CME in November 1997, and using an upper limit on the low threshold scaler rate to constrain the energy of the putative photon excess from GRB970417. In the first case we need to model the scaler response to an isotropic flux of protons, and in the second a gamma-ray flux from a known, small zenith angle. Systematic uncertainties in the simulation of the scaler response is a reasonable concern. The reality checks that we use to test the Monte Carlo results for triggered events (location of moon shadow, predicted sensitivity to a known gamma-ray source, cosmic ray trigger rates etc) are either impossible or much more difficult for scalers. The purpose of this memo is to try and understand the magnitude of systematic errors in the scalers and the effect that they have on our conclusions.

2 Isotropic Protons

Some significant sources of systematic uncertainties which have been extensively discussed in the past are a) We do not throw simulations out to 90 degrees as the version of corsika we were using assumed a flat atmosphere. Thus to simulate an isotropic proton flux we have to assume some extrapolation of the effective area at large zenith angles. and b) There were some concerns about the accuracy of corsika simulations of proton showers below 20 GeV, an energy much below the original primary energy range corsika was designed for. Both these effects will result in systematic uncertainties when simulating the scaler response to isotropic proton flux (for solar studies, or to match cosmic-ray counting rates), but will not affect simulations of the scaler response to low zenith angle gammas. Of course, this is not to say that the systematic uncertainties for gammas is negligible, just that they are likely to be less than for isotropic protons.

Abe Falcone folded the cosmic-ray spectrum with the effective area (for protons) of the high threshold scalers and found that he underestimated the cosmic-ray counting rates by a factor of three. This was a very nice test, as it checks almost exactly the same thing that he actually used in his analysis (isotropic protons). This result gives us a feel for the magnitude and direction of the systematic uncertainty. This migh suggest that our scaler effective areas may be as much as a factor of three larger than returned by the MC. It does NOT indicate that the effective area might be a factor of 3 smaller.

There are a couple of issues that may contribute to this deficit: the effect of heavier nuclei was neglected in the calculation of the effective area. This will lead to an underestimate in the predicted counting rate. Also, the simulations that Abe generated could only be thrown out to 60 degrees, he extrapolated the effective area curve out to 90 degrees. The extrapolation is only reasonable in the absence of effects specific to large zenith angles. However at the October 2000 collaboration meeting Andy and I showed (using simulations out to 75 degrees) that as one decreases the trigger threshold a bump appears at large zenith angles in a triggers vs zenith angle plot. Thus the assumption that there were no new components to the scaler rate coming in at large zenith angles was probably not correct. The plot we showed was for Milagro, Milagrito did not have baffles. We might expect this effect to be more intense for Milagrito as we would expect high zenith angle muons to deposit lots of light into the PMTs. The plot we showed at the collaboration meeting is shown in Figure 1.

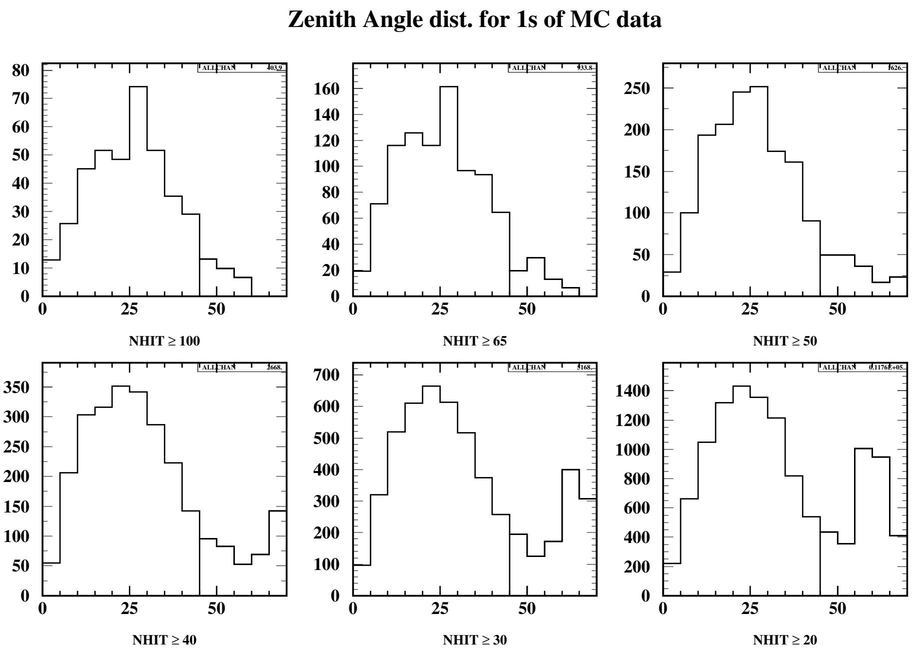

Figure 1: Histograms of proton triggers vs zenith angle for a range of trigger thresholds

3 Possible sources of systematic error

We expect (and see) variations in the scaler response with temperature, pressure etc. Looking at the variation of scaler rates throughout the year gives us a feel for the magnitude of these effects. Figure 2 shows the low threshold scaler rates for the Milagro air-shower layer for 1999, 2000 and 2001. From this plot I estimate that our uncertainty due to not knowing (or not correcting) for atmospheric and seasonal variations is around 20%

I had originally thought that it would be possible to get feel for the magnitude of systematic uncertainties by looking at how our predicted detector response varies when we tweak the simulation. However, many of the tweaked simulations also predict changes in the effective area for triggers (which makes that set of simulations inconsistent with having the correct 100 tube trigger rate.). So while it is true that our scaler response can change sharply when we change scattering properties in the pond (by, for example, removing the air layer between the water and the cover), results in a change in the 100 tube trigger rate which is inconsistent with observations of 100 PMT trigger rate. Another way of saying this, is that all the checks we perform on the MC to constrain the magnitude of the systematic uncertainties for the 100 tube trigger (matching trigger rates etc) also provide information on the magnitude of systematic errors for the scalers.

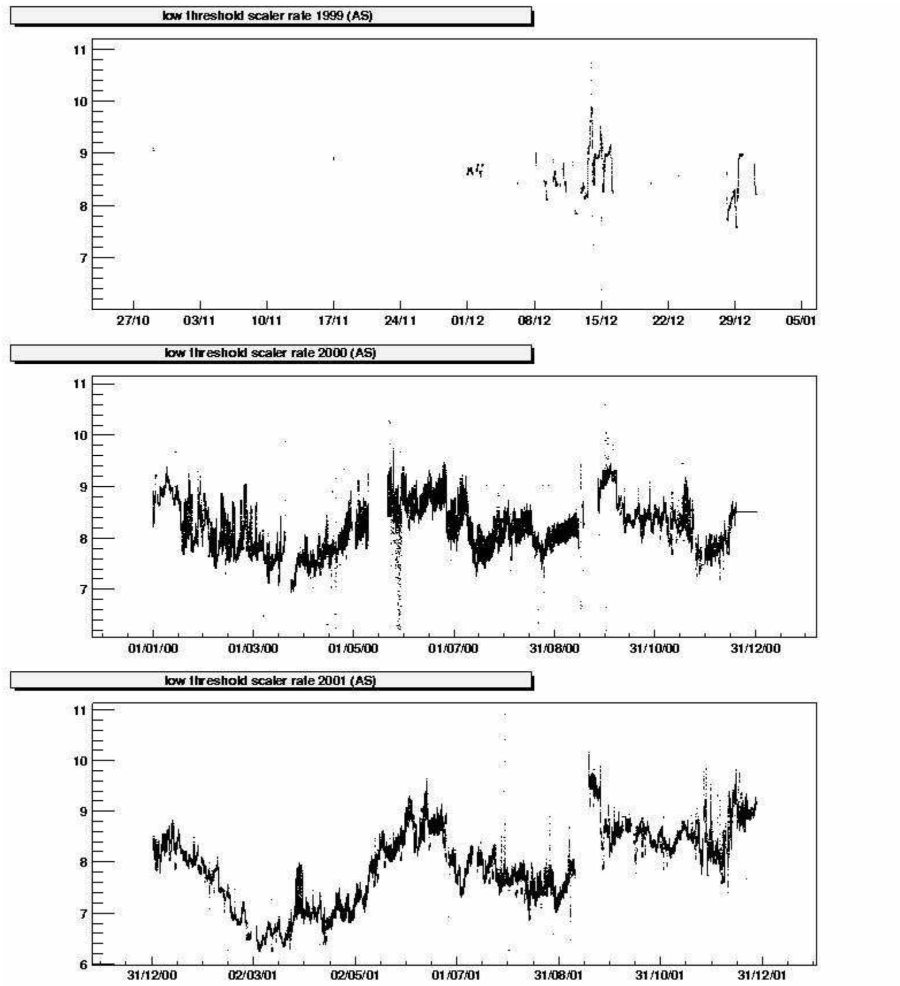

Figure 2: Low threshold scaler rates for 1999, 2000 and 2001

4 Effect of systematic uncertainties on the scaler result for GRB970417

The systematic uncertainty in the scaler effective areas is at least 30%, due to atmospheric/seasonal variations. This is larger than the 20% quoted in the previous section, as it seems likely that gamma-ray showers will be more sensitive than hadron showers to changes in atmospheric overburden (due to the much smaller fraction of muons). Making conjectures from Abes results, it is less than a factor of three, and is more likely to result in an underestimate of the effective areas. A conservative estimate of the systematic error in the effective area calculations for the scalers is a factor of 2. We can look at the effect of this by allowing the effective area to vary from 0.5 to 2 times its nominal value.

Figure 3 shows the effective area versus energy for the low threshold scalers and the

100 tube triggered data. The effective area for the triggered data is defined as:

$$A_{eff} = (\frac{N(trig + fit)}{N(tot)}) \times A_{throw} \tag{1}$$

$N(trig+fit)$ is the number of events which pass the trigger and fit within a 1.6 degree bin. To form the trigger in the simulation data: all the tubes that were dead at the time of the GRB were switched off, the soft trigger turn on function (which is actually rather hard) derived by Stefan was used to decide whether the event passes the trigger, the event then passes through a function (also from Stefan) which simulates calibration losses (by randomly removing PMTs). The event is then sent to the angle fitter (after curvature and sampling corrections).

Rather than deriving limits on upper cutoff energy as a function of spectral index, I will focus on one special case. That of a monoenergetic flux. This is the point that the cutoff/spectral index plot asymptotically approaches (as the spectrum becomes steeper the effective area becomes increasingly dominated by the value at the upper energy cutoff). Which is why we claim that a spectral independent minimum energy can be obtained from this plot.

If $A_{trig}(E)$ is the effective area of the triggered data at an energy E, then the monenergetic flux ($F(E)$) required to give 13.3 events in the signal bin is given by:

$$F(E) = 13.3/A_{trig}(E) \tag{2}$$

The predicted number of scaler counts produced by $F(E)$ is given by:

$$N(scalers) = F(E) \times A_{scalers}(E) \tag{3}$$

As we move from lower to higher energies, the sensitivity of the scalers relative to the sensitivity of the 100 tube triggers decreases. The upper limit on the low threshold scaler counts was 67000. We can find the energy (E_{min}, for which $F(E_{min})$ gives 13.3 signal events in the triggered data and 67000 scaler counts. Energies below this result in a prediction of more than $N_{upper}(scalers)$ and are thus excluded by the scaler upper limit.

So what do we see? For the effective area curves shown above, E_{min} is 650 GeV, if I decrease the scaler effective area by a factor of 2 E_{min} drops to 350 GeV, if I double the scaler effective area E_{min} increases to 1.26 TeV. If we assume that the systematic errors are of order 30% which may be a more reasonable estimate of the systematic errors, then E_{min} can range from 470 GeV to 820 GeV.

What about the effect of systematic uncertainties in the energy scale? The same simulation is used for both the scalers and the triggered response curves, the only substantial difference is the trigger threshold. The systematic errors in both datasets are correlated. Thus if we are systematically too high in energy by 30% in the triggered data, then we are likely to be 30% too high for the scalers also. This will make E_{min} too high by 30%. If the errors in the energy scale were different (in magnitude or direction) for scalers and triggered data, then the effect on E_{min} would be larger, but this is not a reasonable assumption.

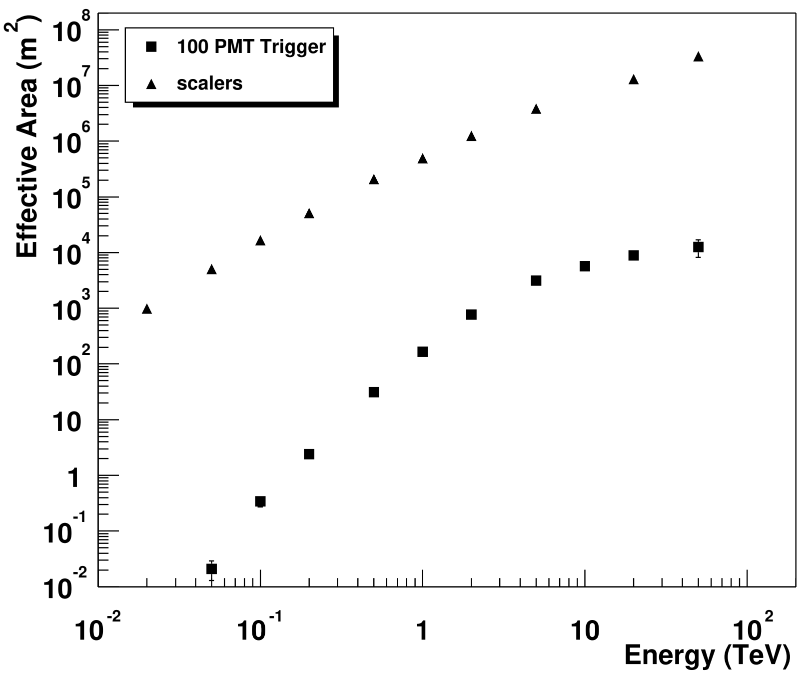

Figure 3: Effective area versus energy for low threshold scalers and 100 tube trigger data