Internal Report

DIR-7-83

HOW MUCH CAN WE IMPROVE SENSITIVITY OF MT. HOPKINS GAMMA RAY TELESCOPE?

V.J. Stenger
University of Hawaii
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In DIR-3-83 I show, from running Monte Carlo events through GRIM, that under the operating threshold of 60 pe on at least 3 of the inner 7 PMTs we can expect about 0.6 events per min above 300 GeV, with a peak in the spectrum at 2 TeV, for an incident gamma flux of 1 $km^{-2}\, s^{-1}$ above 1 TeV.

This assumed 100% reflectivity for the 10m mirror. Since the actual reflectivity has been about 40%, the actual spectral peak is at about 5 TeV and the threshold energy about 750 GeV. The integrated event rate, for the same flux, is about 0.2 events per min above 1 TeV.

In the same note I also showed that the angular resolution, without imaging, is 0.75°. If the efficiencies for proton and gamma shower detection are identical and taking a primary proton flux of $10^{6} km^{-2}\, s^{-1}\, sr^{-1}$ above 1 TeV we get a proton shower rate of

$$10^{6}\,(0.75/57.3)^{2}60 = 34\ \mathrm{min}^{-1}$$

which agrees with observation.

More generally, if S is the signal rate, N is the background rate, T is the observing time, then for a 4σ effect $ST = 4\sqrt{NT}$, or

$$T = 16N/S^{2}$$

Thus, for N = 34 and S = 0.2 an observing time T = 9 days is required to see a signal at the assumed level. Since the typical advertised sensitivity for the atmospheric Cerenkov technique is 0.1 $km^{-2}\, s^{-1}$ above 1 TeV, the stated operating conditions give at least an order of magnitude worse sensitivity than the typical detector! I find it hard to believe that our basic system, without imaging, is that bad compared with older experiments. I prefer to think that other authors have not been realistic in their estimates of sensitivity.

In any case, we have advertised that we can do 10 times better than typical with imaging. Let us see what we can hope to achieve with imaging and other improvements.

Let me write

$$S = F_{\gamma}\,\epsilon_{\gamma}A$$

where F_γ is the gamma flux, ϵ_γ is the efficiency for gamma detection and A is the collection area. Similarly

$$N = F_p \epsilon_p A$$

where ϵ_p is the proton detection efficiency. From above

$$S = 0.2 F_\gamma \eta_\gamma \ \text{min}^{-1}$$

where η_γ is the gamma detection efficiency relative to the efficiency under the specific conditions assumed above.

The noise rate can be similarly expressed

$$N = 34(\delta\theta/0.75^{\circ})\eta_\gamma \xi_p \ \text{min}$$

and $\delta\theta$ is angular resolution.

where ξ_p is the detection efficiency for protons relative to gammas. This may seem overly complicated, but I think it is useful to distinguish two things: the detection of showers and the rejection of protons.

Putting all this together we get the detectable flux for an observing time T:

$$F_\gamma = (9 \ \text{days}/T)^{1/2}(\delta\theta/0.75^{\circ})(\xi_p/\eta_\gamma)^{1/2}$$

$km^{-2}s^{-1}$ above 1 TeV.

So what can we do to reduce F_γ ?

1. Observing Time. As the system becomes more stable we can improve somewhat here. But given the transient nature of the sources we cannot expect to learn much about the source until we can achieve a high sensitivity for fairly short observing times.

2. Angular Resolution. Improvements on angular resolution enter linearly. We had once hoped to achieve a factor of ten. Current indications are that, at the very least, a factor of 3 here is likely, by imaging.

3. Gamma Efficiency. When one separates out the proton rejection factor as above, this enters as the square root. As I show in DIR-3-83 the gamma efficiency is very low under the tight triggering used in the early observations, typically a few percent. Looser triggering, which does not at the same time increase ξ_p, should be possible which will increase this a factor of 3 or 4, or perhaps more.

4. Proton Rejection. This enters as the square root. We want ξ_p as small as possible. Imaging can hopefully be used here to distinguish proton showers from gammas, on a statistical basis of course. However, the results on Cyg X-3 presented at Bangalore (paper XG4-12) suggest that the improvement obtain by imaging is not one of shower recognition, e.g., double cores, but one of shower pointing, i.e., angular resolution. Other possibilties, such as gamma showers being "tighter", may work but I maintain that we cannot conclude this by a comparison of Monte Carlo and data until we are sure of our calibar-

ation and trigger the Monte Carlo events in exactly the same way as the data. I would expect that a factor of 2 or 3 in proton rejection by imaging is possible.

It is also possible to help reject protons by hardware schemes. Perhaps a fast coincidence trigger with the 3m can greatly reduce γ_p without reducing η_γ. This is the concept of the Athens, Wisconsin, Purdue, Hawaii experiment to go on Haleakala, Maui.

In summary, a factor of ten or more improvement in flux sensitivity is possible with a combination of changes to the Mt. Hopkins system. To achieve this we need a factor of 3 or more from each of three factors: angular resolution by imaging, proton rejection by imaging, gamma shower detection by looser triggering. That is,

$$F_\gamma \rightarrow (9\ \text{days}/T)^{1/2} (.25^\circ/.75^\circ)(.33/3)^{1/2}$$

$$= 0.1(9\ \text{days}/T)^{1/2} \quad \text{km}^{-2}\ \text{s}^{-1} \text{ above 1TeV.}$$

Other schemes, such as fast coincidence, can make further improvements.