SHOWER DISC SAMPLING AND THE ANGULAR RESOLUTION OF γ-RAY SHOWER DETECTORS

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ABSTRACT

As part of our design study for the new UHE γ-ray detector being constructed at Haverah Park (1), we have undertaken a series of experiments using scintillators operated side-by-side in $> 10^{15}$ eV air showers. Investigation of the rms sampling fluctuations in the shower disc arrival time yields an upper limit to the intrinsic sampling uncertainty, $\sigma_{rms} = (1.1 \pm 0.1)$ns, implying an angular resolution capability $< 1^o$ for an inter-detector spacing of ~ 25 m.

1. Introduction. That an angular resolution of $1.5^o - 2.0^o$ can be achieved by extensive air shower arrays was shown conclusively by the identification of Cyg X-3 as a source of UHE ($> 10^{15}$ eV) γ-rays (2). Subsequent confirmation (3) and reports of detections of Vela X-1 (4) and LMC X-4 (5) have highlighted the need for a new generation of arrays with a much improved detection signal to noise ratio.

The prospects for detecting a source improve with increasing collecting area, exposure time, or knowledge of source periodicity, but most acutely with improved directional resolution, especially in view of the fact that periodic γ-ray sources are likely to be time variable and lack a constant phase maximum (e.g. (6)), thereby precluding extended observations.

Here we concentrate on an experimental determination of the angular resolution achievable by the new γ-ray detection system in construction at Haverah Park (1).

2. Description of the detectors and the recording system. We have studied the extensive air shower disc at energies $10^{15} - 10^{16}$ eV using two 1 m^2 plastic scintillation detectors in conjunction with a 50 m water-Cerenkov array. Because this work formed the initial stages of the design study for the new array, the scintillation detectors were not identical in construction. The 'start' detector consisted of 1 m^2 type NE102A 7.6 cm thick scintillator, viewed from below at a distance 61 cm by a Philips 2312B 3"ϕ PMT, risetime < 3 s . The 'stop' detector consisted of 1 m^2 type (see (7)) 9 cm thick scintillator viewed from above at a distance 38 cm by an EMI 9821B 3"ϕ PMT, risetime < 3 s . We found it essential to blacken the entire detector interior to eliminate multiple reflections ensuring that the PMT views only the direct light from the scintillator.

The scintillators were situated at the centre of the 50 m water-Cerenkov array used to provide the EAS trigger, and, in subsequent analysis, the shower arrival direction, size, and core position. A block diagram of the arrangement is shown in Figure 1.

A variety of detector configurations, shown schematically in Figure 2 were used to investigate the timing response in EAS and also for a loose trigger condition (termed "single particles") in which both detectors were required only to exceed the $^1/_3$ particle discrimination level.

3. Detector and recording system limitations. The combined limitation of the detectors and recording electronics was investigated using both the loose trigger and vertical showers at small core distances, experiments (4) and (1) of Figure 2 respectively. A rapid increase in the standard deviation of the time delay, $\sigma(\Delta t)$, at smaller densities was found, due partly to the leading-edge type of discrimination employed and also some electronic cross-talk at low voltage levels which has since been eradicated. For densities>1.6 particles m^{-2} the intrinsic timing resolution of the detector and recording electronics was constant at $\sigma(\Delta t) = 0.89 \pm 0.09$ ns. The identical detector configuration, in response to 50 m shower triggers with zenith angles, $\theta < 10^{\circ}$, core distances, $r < 25$ m, and both scintillator densities $> 1.6\, m^{-2}$ gave $\sigma(\Delta t) = 0.92 \pm 0.11$ ns, which is not significantly different to the intrinsic resolution. A density threshold of 1.6 particles m^{-2} has consequently been imposed for the remaining analysis.

4. Scintillator timing response in 10^{15} eV showers. Two independent samples of the shower front at the same core distance were obtained with side-by-side detectors (Figure 2, experiment (3)). Separating the detectors by 3 m (experiment (2)) allowed for the effect of small core distance differences to be investigated. Even when side-by-side, the time delay between detectors, Δt, must be corrected to allow for the transit time of the shower disc through the detector centres. The 50 m water-Cerenkov array determines the shower direction to an accuracy of $\lesssim 5^{\circ}$, which is quite adequate for this correction to be made. Figure 3A shows the mean time delay $\overline{\Delta t}$, before and after correction, for a sample of showers in four azimuth angles defined in Figure 3 . After correction the $\overline{\Delta t}$ are consistent with expectation.

5. Time structure of the particle disc. The standard deviation of the time delay distribution, $\sigma(\Delta t)$, is directly attributable to rms fluctuations of the distance into the shower front at which the detectors trigger. We expect $\sigma(\Delta t)$ to increase at larger core distances due to the decreasing particle density and increasing shower front thickness. Figure 4 shows $\sigma(\Delta t)$ as a function of core distance; superposed are lines representing angular resolutions of $\pm 1^{\circ}$ and $\pm 0.5^{\circ}$. The results indicate that an angular resolution of $< 1^{\circ}$ may be achieved. This is in good agreement with the predicted angular resolution obtained from an empirical relationship derived by Linsley (8). Figure 4 also shows that the angular resolution is practically independent of core distance, at least out to 75 m, the improved baseline compensates completely for the effect of a rising $\sigma(\Delta t)$.

6. Discussion. Little, albeit careful, previous work has been done on the sampling of the EAS disc. Bassi, Clark and Rossi (9) obtained thickness $\sim 2-3$ m for core distances < 60 m and shower sizes $10^5 - 10^6$. More recent work, by the Kiel group (10,11) aimed to measure the longitudinal profile and curvature of the disc in small air showers. They reported a radius of curvature of 600 m for the electron disc with respect to the muon disc at energies $\sim 10^{15}$ eV (10). The limitation of the present work is that although $\sigma(\Delta t)$ reveals the magnitude of the timing

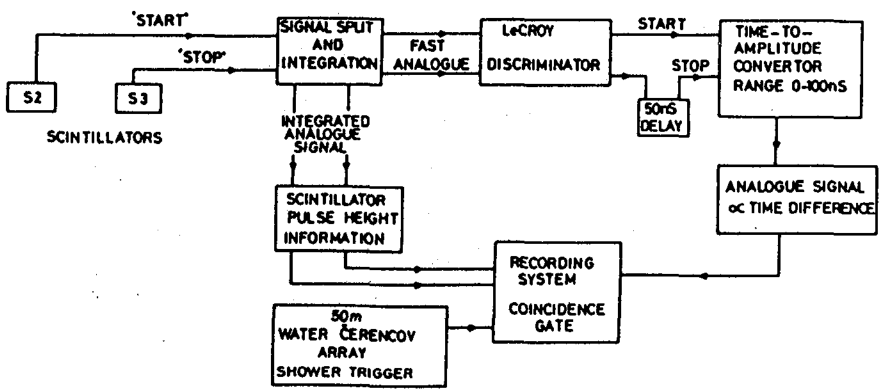
fluctuations, we cannot determine the presence of a systematic curvature of the disc. We emphasise this since it is of paramount importance in assessing the attainable angular resolution; the effect of neglecting a curvature of 600 m is to increase the angular uncertainty by $\sim 3^o$. An accurate correction for curvature in individual showers requires many detectors surrounding the shower core. Of the 32 detectors in the new Haverah Park array (1), 14 are located inside a radius of 50 m on a 25 m grid spacing, providing a powerful facility for the future investigation of curvature.

We note that the results discussed are for nucleon-induced showers. The expected absence of a prompt muon front in γ-ray initiated showers may worsen the attainable resolution.

7. Conclusions. We have shown that the scintillation detectors designed for use in the new Haverah Park array (1) have a timing resolution of better than 1 ns. An investigation of their performance in small air showers leads us to expect an angular resolution of $< 1^o$ for this array.

Figure 1

BLOCK DIAGRAM OF SETUP



TIME-TO-AMPLITUDE CONVERTER : EG&G ORTEC MODEL TH200A/N

LeCROY DISCRIMINATOR : MVL 407 TB QUAD

Discriminator threshold $\sim 1/3$ particle m^{-2}.

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Figure 2

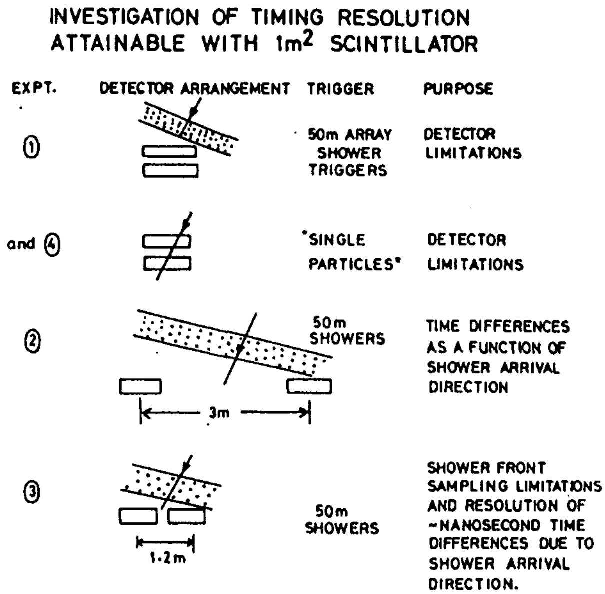

Figure 3

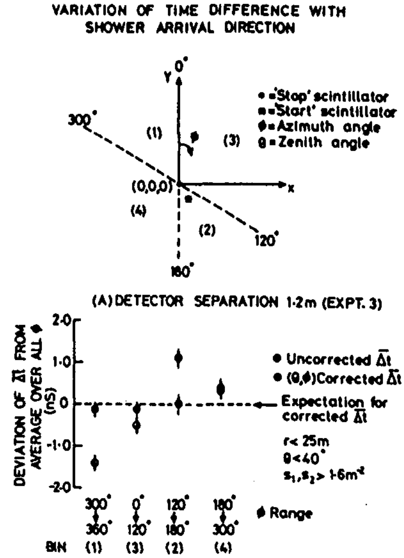

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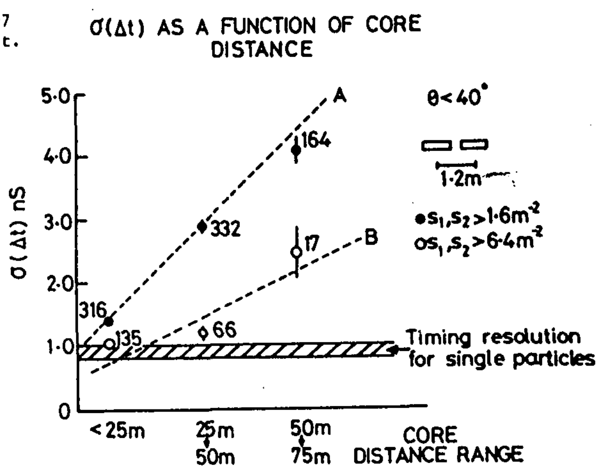
Figure 4



The region below the dotted line represents the timing resolution resulting in an angular error: A±1°, B±0.5°