Aust. J. Phys., 1988, **41**, 93–9

A Search for Tachyons in Cosmic Ray Showers

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Abstract

A search has been made for tachyons associated with cosmic ray showers of energies about 10^{15} eV by searching for any precursor effects observed in plastic scintillator detectors. Detection thresholds well below most other similar experiments have been reached but no statistically significant effects have been found.

1. Introduction

The speed of light holds a central position in physics. It is an unattainable barrier for familiar particles with a finite rest mass and it is the speed of particles with zero rest mass. If there are particles with speeds greater than that of light, they may have an imaginary rest mass to complete the triad. The latter superluminal particles would be known as tachyons.

It is close to a century since the problem of superluminal charged particles was first considered by Heaviside (1892) and Thomson (1889). Their analyses exhibited properties basically similar to those which finally became clear when Frank and Tamm (1937) explained Cerenkov radiation, the result of charged particles travelling faster than the local speed of light. It is well worth bearing in mind that superluminal speeds are not unphysical, it is speeds greater than light in vacuum that are controversial. Indeed, a form of time reversal, a tachyon property, is commonly observed in the optical study of cosmic ray showers in the atmosphere.

The concept of the vacuum speed of light as a barrier came with Einstein's relativity and, particularly, with the concept that energy and mass have an equivalence and the energetic impossibility of accelerating a massive particle to the speed of light. There are no problems of principle with the production of particles with the speed of light. Photons with zero rest mass naturally have that speed. Neither has there been any particular conceptual difficulty in having photons interact with their slower partners. It is conceivable that, in a similar sense, tachyons may be created with speeds greater than light and they may then interact with conventional particles, possibly through zero rest mass intermediate particles. The possibility of this third class of particles was discussed by Bilaniuk *et al.* (1962) and the idea developed by Feinberg (1967). The theory of tachyons was reviewed and extended by Recami and Mignani (1974).

0004-9506/88/010091$03.00

2. Some Searches for Tachyons

Clearly, it is possible to search for tachyons by measuring their velocity in some way. However, there may also be other observable properties of such particles which are related to their superluminal speed.

It is possible that charged tachyons might emit Cerenkov radiation, similar to any other charged particle which exceeds the local speed of light (Alvager and Kreisler 1968). This may occur under all circumstances, even in a vacuum, although there has been debate over this point (see e.g. Ey and Hurst 1977; Agudin and Platzeck 1982). If so, it may be possible to search for light emission when particles traverse a vacuum. Such searches have been made. Since Cerenkov radiation represents an energy loss mechanism these experiments have involved searching for Cerenkov radiation in the electric field between two electrodes which are arranged to produce a voltage gradient appropriate to replenishing the radiated energy.

An alternative search technique is to assume the correctness of special relativity when applied to tachyons. The mass of the tachyon is now an imaginary number and its square is negative (Alvager and Kreisler 1968; Baltay *et al.* 1970). Measurements have been made of missing mass squared in particle reactions as a test for the possible production of uncharged tachyons. These searches depend on several assumptions concerning the interactions of tachyons, but it is not then necessary to directly detect the tachyon itself or to know how the tachyon propagates through matter.

3. Searches for Tachyons in Cosmic Ray Showers

Experiments which search for precursors to atmospheric cosmic ray showers are conceptually simple and almost unambiguous. There are few ways in which nature could perversely present us with events which are associated with such showers and yet arrive substantially before the shower itself. A shower consists of highly relativistic particles and it effectively travels at the speed of light in vacuum. Thus, the shower provides a speed of light reference. Shower particles which arrive substantially before the main shower front would be associated with tachyons. They would either be tachyons themselves or particles resulting from earlier tachyon interactions.

Interaction properties of tachyons are unknown and there is a huge 'phase-space' of potential detector designs: perhaps one must use material placed above the detector in which tachyons might interact and produce detectable particles; perhaps one must reduce the detector wall thickness as much as possible to allow entry of tachyons; perhaps tachyons will not interact with conventional detectors so that an unconventional design is required such as that by Alvager and Kreisler (1968). The tachyon signal may be much bigger, or perhaps smaller, than that of a conventional particle. A result of such conjectures has been that a number of detectors designs have been employed in tachyon searches but, in general, they have been rather conventional and it may be that the correct design lies elsewhere in the unknown design phase-space.

The first experiment of this type was conducted by Ramana Murthy (1971) and most later experiments have used an elaboration of his technique. Cosmic ray air showers are particle cascades generated in our atmosphere by primary cosmic ray particles. A typical altitude for the primary interaction is $\sim$10–20 km and, for a vertical shower, this corresponds to a cascade propagation time of $\sim$30–60 μs. These showers are typically observed within 30° of the zenith so a maximum likely time for a tachyon generated in a shower to precede the shower front at sea level would be $\sim 80\ \mu s$. If there is an energy threshold for tachyon production then one would expect a signal in the period of perhaps ~ 30–$80\ \mu s$ before the shower. If there is no threshold, one might expect a signal covering all times up to $\sim 80\ \mu s$, with a preference for short to intermediate intervals since the shower particle size reaches a maximum at intermediate altitude (~ 5–10 km) and then slowly decreases to sea level.

Ramana Murthy (1971) examined the time period up to $\sim 20\ \mu s$ before the shower front. In practical terms he chose potential tachyon triggers and then looked for a shower in the following 20 μs. He compared the number of observed events with an expected number based on a random sample of the long term shower rate. Also, he examined the time distribution of the following showers over the interval of interest.

The technique was developed by Clay and Crouch (1974) who introduced the use of transient recorders to tachyon searches. These digital oscilloscope instruments have a 'pre-trigger record' facility which allows signals preceding the trigger to be easily studied and thus enable one to study long periods before shower triggers without the need for long analog delay lines and their inherent bandwidth limitations. Clay and Crouch triggered their transient recorder with air showers and searched for non-random effects in a scintillator, originally up to 105 μs before the shower front. This search was repeated using random triggers for comparison. Although they found an apparent positive effect, Prescott (1975, 1976) later showed that much of the apparently high statistical significance of this result was due to an experimental bias associated with overshoot in the scintillator signals. When due allowance was made for this, the significance was reduced from the 0·01% level to the 4% level.

As a result of this apparently positive result, a number of experiments were performed in a generally similar manner but with no clear confirming result. Ashton *et al.* (1977) briefly reviewed these experiments (Emery *et al.* 1975; Fegan *et al.* 1975; Hazen *et al.* 1975; Smith and Standil 1977) and pointed out that such experiments had generally searched for shower precursors which were detected at much lower signal levels than those produced by single relativistic muons. In these experiments, a signal corresponding to the detection of a potential tachyon was generated and the time of this signal before a following shower was measured. It had been usual practice to generate the potential tachyon signal at quite a low level since there was no real *a priori* information on what detector output a tachyon might be expected to produce. As a result, many spurious triggers would be generated and might well mask a rare tachyon signal. Ashton *et al.* (1977) and later Bhat *et al.* (1979) searched for large output pulses from heavily shielded detectors and, while Ashton *et al.* found an apparent excess due to large pulses, this was not confirmed by Bhat *et al.*

The experiment by Clay and Crouch (1974) only exploited part of the true potential of the transient recorder as it was not possible at that time to transfer data to a computer for automatic averaging. Some hundreds of events were summed by hand. This averaging was subsequently carried out by Fegan (1981) and by MacNeill and Fegan (1983), and will be investigated below in Section 4.

Fegan (1981) added many signals point by point relative to the arrival of the shower front and produced summed signal amplitudes as a function of time before the shower. He first used a system sensitive to signal levels below those expected from a single relativistic charged muon. There was a suggestion that his data might contain an excess in the period 40–80 μs before the shower front arrival. Moreover, it appeared that the excess was due to a small number of large pulses rather than a sum of a large number of small contributions. This work was then continued by MacNeill and Fegan (1983) who searched for any excess in pulses with amplitudes at least as great as minimum ionising particles, up to 100 times the amplitudes studied by some previous experiments. The result was that rather more events (1·44 times) were found in the 100 μs immediately before the shower than in the 100 μs preceding this, compared to a 'random' ratio of 1·22 obtained with the same recording system. This was not regarded as significant evidence for any precursor events, due to large statistical uncertainties in the data set. A total of only 49 events was observed in the 100 μs directly preceding the trigger point and only 667 control data sets were recorded to derive a comparison ratio.

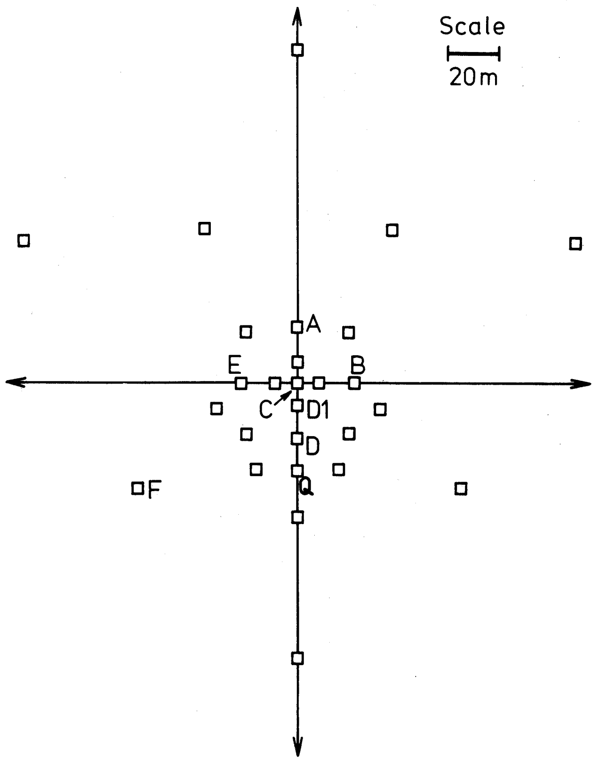

Fig. 1. Plan of the relevant parts of the Buckland Park air shower array. Detectors A, B, C, D and E were used as a 'fast trigger'. Detectors F and D1 were used in the search for tachyons. Detectors Q and A were used in coincidence as a trigger for higher energy showers.

4. Experimental Work at Buckland Park

The present experimental work was based at the air shower array operated by the University of Adelaide at its Buckland Park field station (Crouch *et al.* 1981). A number of experiments, previously unpublished, have been performed as the work developed.

The first experiment reported here employed the detection system used by Clay and Crouch (1974), a 1 m^2 scintillator and a preamplifier with 500 ns rise time, ~ 5 μs fall time, and overshoot with a time constant of ~ 50 μs. The detector employed was F of the air shower array (see Fig. 1) and the recording system was triggered by a 'fast array' coincidence, a coincidence between detectors A, B, C, D and E at the two particle level. The six-bit digitising Biomation 610 of the Clay and Crouch experiment was used and its output for each event was transferred to a microcomputer and accumulated immediately as a stored sum for each 1 μs interval of the record. The pre-trigger record delay was set so that ~ 170 μs before the shower arrival was recorded and thus a period of pre-tachyon signal was included along with the potential tachyon period. A total of $\sim 25\,000$ events was recorded in this way with a mean air shower energy of $\sim 2\times10^{15}$ eV. The resulting summed distribution is shown in Fig. 2*a*.

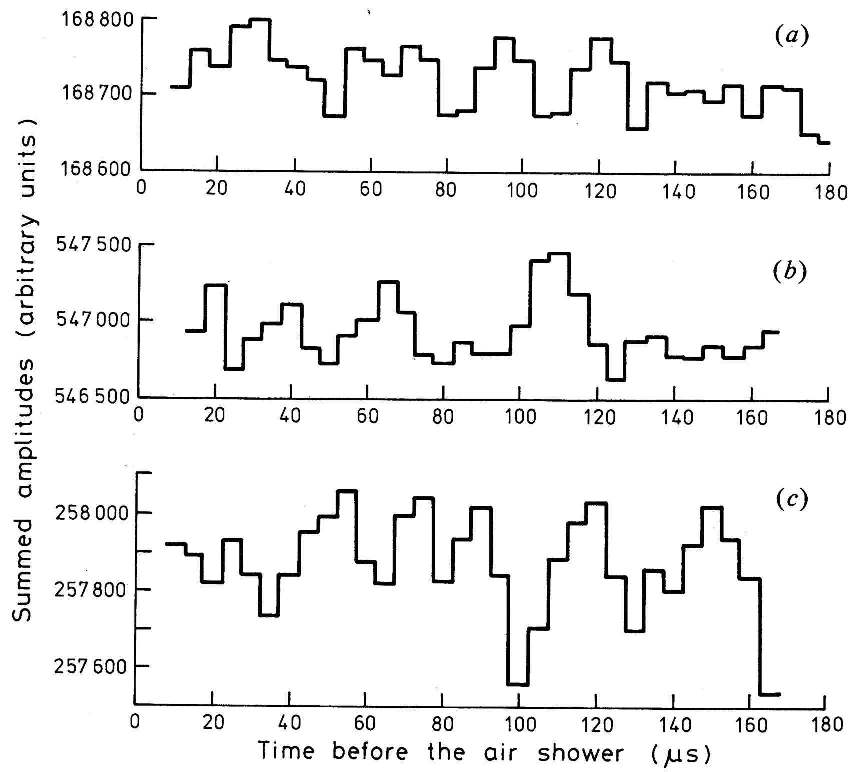

Fig. 2. (*a*) Sum of the signals for $\sim 25\,000$ events using the F detector. The signal impulse response had a width of ~ 5 μs with ~ 50 μs overshoot. Mean shower energy was $\sim 2\times10^{15}$ eV. Note that since individual digitised events may have nonzero offsets, the total summed amplitude should not be interpreted in a simple physical manner.

(*b*) Summed signals from the D1 detector for $\sim 90\,000$ events using non-overshooting amplification with an impulse response of ~ 15 μs width. Mean shower energy was $\sim 2\times10^{15}$ eV.

(*c*) Summed signals from the D1 detector for $\sim 21\,000$ events using non-overshooting amplification with an impulse response of ~ 15 μs width. Mean shower energy was $\sim 10^{16}$ eV.

There is an inherent problem with the data of Fig. 2*a* in that, since the pulse of a single particle has a 5 μs fall followed by a 50 μs compensating overshoot, the total accumulated area of the figure for tachyons will average out. One is then left with a response only to narrow time peaks or, for an extended time distribution, one has a differential summed signal with a differentiating time constant of order of 50 μs.

A non-overshooting amplifier was therefore constructed and the preceding experiment repeated, this time in conjunction with one of the larger $2\cdot25\ m^2$ scintillators (D1 in Fig. 1) of the newly extended Buckland Park array. The new amplifier has a total positive pulse output width of $\sim 15\ \mu$s with minimal negative overshoot so that the impulse does not average in any way to zero in the time period under study. A second experiment was then performed with again a 'fast array' trigger and $\sim$90 000 events were accumulated. The resulting distribution is shown in Fig. 2*b*.

It is possible that there could be an energy threshold for the production of tachyons and I have carried out a third search for tachyons, this time with a higher shower size threshold. The mean shower energy in this case was $\sim 10^{16}$ eV and a total of $\sim$21 000 events were accumulated with the same non-overshooting recording system used before (Fig. 2*c*).

Table 1. Results obtained in the Buckland Park experiments

Expt	Fig.	Estimated MSPE[A] (eV)	Mean core distance (m)	No. of events	Excess amplitude[B]	Ratio[C]
1	2*a*	2×10^{15}	$\sim$90	$\sim$25 000	800 ± 350	$3(\pm1\cdot5)\times10^{-2}$
2	2*b*	2×10^{15}	$\sim$30	$\sim$90 000	75 ± 100	$2(\pm2\cdot5)\times10^{-4}$
3	2*c*	10^{16}	$\sim$50	$\sim$21 000	70 ± 150	$3(\pm7)\times10^{-4}$

[A] Estimated mean shower primary energy.
[B] Excess amplitude in 60 μs preceding the shower (equivalent particles).
[C] Ratio of tachyons to conventional particles.

5. Discussion of the Results

The results obtained in the Buckland Park experiments are summarised in Table 1. The estimated signal in the tachyon period (0–60 μs before the shower) was estimated on the basis of the signal in the previous 90 μs. Calibration by accumulating single muon signals allowed an estimate to be made both of any tachyon excess in terms of equivalent particles and also of the fraction of tachyons to the total shower particles.

There is no statistically significant evidence for the observation of tachyons in any of the observations. In each case, the sum of the signals in the tachyon period exceeds the scaled sum in the earlier 90 μs period despite careful checks to search for any instrument bias. This result, a non-significant excess in the tachyon period is consistent with the more recent results obtained by Fegan (1981) and by MacNeill and Fegan (1983). A small excess was also found in a pilot project for the present work (Sennett and Trowse 1981).

6. Conclusions

Searches have been made for evidence of tachyons associated with cosmic ray showers of energy 10^{15}–10^{16} eV. No positive evidence has been found using conventional scintillation detectors for producing a tachyon signal. These showers have typical particle sizes of $\sim 10^5$–10^6 and upper limits can be set of ~ 10 tachyons per shower.

Acknowledgment

Neville Wild designed and constructed the non-overshooting amplifier.

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Manuscript received 16 June, accepted 1 September 1987