

On the Origin of Coincident Delayed Scintillator Pulses Observed with an EAS Array

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Abstract

The origin of delayed scintillator pulses observed with a small air shower array at the University of Turku, Finland, has been investigated. The triggering system of the array allowed delay time measurements in the region from 10 ns to 250 ns. The basic question is, whether these pulses are related to physical origin (e.g. delayed showers) or to technical origin (photomultiplier afterpulses etc.). The results of data analysis are presented and possible explanations are given.

1 Introduction

The origin of the delayed scintillator pulses in extensive air showers is not clear. Many investigators have proposed different explanations for this phenomenon. During the 1980's many investigators presented some evidence for massive hadrons in air showers. Investigators also attributed delayed pulses to extreme fluctuations in the arrival time, afterpulses in photomultipliers and random coincidences. Yodh et al. (Yodh, 1987) claimed that the interpretation of the data requires detailed simulations which include all experimental effects such as afterpulsing, shower fluctuations, energy deposit fluctuations etc. before the significance of any positive result can be estimated.

2 Detector

The regular measurements of delayed scintillator pulses with the air shower detector at the University of Turku, Finland (at sea level) commenced in October, 1993. The data acquisition continued until December, 1994. The apparatus was sensitive to air showers of primary energy 0.7-30 PeV. The measurement system consisted of an air shower array (efficient area 400m²) and a hadron spectrometer. The layout of the apparatus was described in (Arvela & Elo, 1995). The shower size and axis location were determined by recording the charge of the density detector scintillation pulses. The angles of incidences of the showers were determined by four fast timing detectors (FT). Three of the FT detectors were situated at a distance of 11 m from the central FT detector. The photomultiplier pulses were fed through discriminators into a time-to-digital converter unit (TDC) operated in a double hit mode. The coincidence of all four FT detectors was needed to trigger the air shower array data collecting routine. The time delay between the main FT detector pulse and the delayed pulse could be recorded with a resolution of 1 ns.

The triggering system allowed delay time measurements in the region from 10 ns to 300 ns. The converter started counting after one of the input channels had received a pulse and stopped counting after receiving the stop pulse. The TDC was cleared automatically with the stop pulse about 350 ns after the air shower trigger pulse.

3 New Analysis

The first results of the delayed pulse analysis were presented in (Arvela, & Elo, 1995). The analysis was carried out more thoroughly in (Arvela, 1997). We shall give some results of these earlier observations below. We studied time distributions of three outer FT detector delayed pulses as measured with real air

showers. All these analyses were done with "good" showers. The definition of a "good" shower means a shower that can be analysed reliably (sufficient statistics, shower core located inside the array etc.). In (Arvela, 1997) we found that the probability of detecting delayed pulses as a function of particle number in the FT detectors was seen to be constant in the delay range <100 ns and was seen to increase in the range <300 ns with an increasing particle density, and we concluded that small delays were hardly due to photomultiplier afterpulses (the frequency of afterpulses should increase as a function of pulse height detected in the photomultiplier). The delayed pulses near 250 ns could be explained with reflected pulses in the cables in individual detectors.

In order to enlarge the statistics, we also included for the analysis all the shower events that met the triggering criterium of the array. Thus, we withdrew the call for "good" showers. Now, we have a collection of 120000 showers instead of 2000. Of course we miss the information about the shower size, core location and arrival direction in this case.

The average time distribution of the three outer FT detector pulses, as measured with showers described in the previous paragraph, is shown in figure 1. The longest delays (> 300 ns) are not accepted for the analysis because they can be mixed with stop pulses. The FT detector signal cable length was 25 meters, so even a small impedance mismatch (some per cents) might produce a delayed pulse near 250 ns if the amplitude of the main pulse is high enough to produce a reflected pulse which exceeds the triggering threshold of the TDC. Near this delay region, a narrow peak can be found (220 ns). Another peak can be found in the range 20-80 ns. The three outer FT detectors were used for delayed scintillator pulse searching, because they are physically similar. The central FT was omitted in the analysis.

It is important to check whether delayed pulses exist simultaneously in more than one detector. We examined the following case: every outer FT detector registered delayed pulses within a coincident time window 20 ns (standard deviation). The delay time distribution of these events (triple coincidences) below 250 ns are shown in figure 2. The familiar 220 ns peak is clearly visible, but in the small delay range only a few coincident events can be found.

To determine the frequency of random triple coincidences, the average of the three individual time distribution curves of the FT detectors was examined. We calculated the probability P of detecting a delayed pulse within a time window (20 ns) as a function of delay time for a single FT detector. Then the probability of detecting delayed pulses in three scintillators is P^3 . Finally, the number of estimated triple coincidences were compared to the measured number of coincidences. The numbers proved to differ from each other at least by one or two magnitudes, indicating that random coincidences were not responsible for coincident delays (table).

Table: Comparison of estimated triple coincidences with the measured number of coincidences.

delay range	$P^3(\text{random})$	$P^3(\text{real})$
0-150 ns	0.00065 %	0.004 %
200-250 ns	0.0023 %	0.46 %

We notice that in the range 200-250 ns $P^3(\text{real}) \gg P^3(\text{random})$. We also noticed that the probability of coincident delayed pulses are generally higher than presented in (Arvela, 1997), but this property can be explained with the smaller average size of air showers in the new analysis.

4 Discussion

As a conclusion we can report the following. The measurements show that coincident delayed pulses originate from a mechanism that produce simultaneous pulses detectable in several detectors. Pulse reflections might explain the peak near 220 ns. Another possible explanation could be e.g. crosstalk in the data acquisition system. Crosstalk may also result in "parasitic" triggering of the air shower detector (in fact we have recorded quite many showers with very small particle densities in the density detectors). High

particle densities increase the probability of crosstalk. Extreme fluctuations in shower development might also be responsible for coincident delays in some cases.

Finally, we would like to emphasize that before finding new particle physical interpretation we should always exclude possible explanations with the properties of the measuring device.

References

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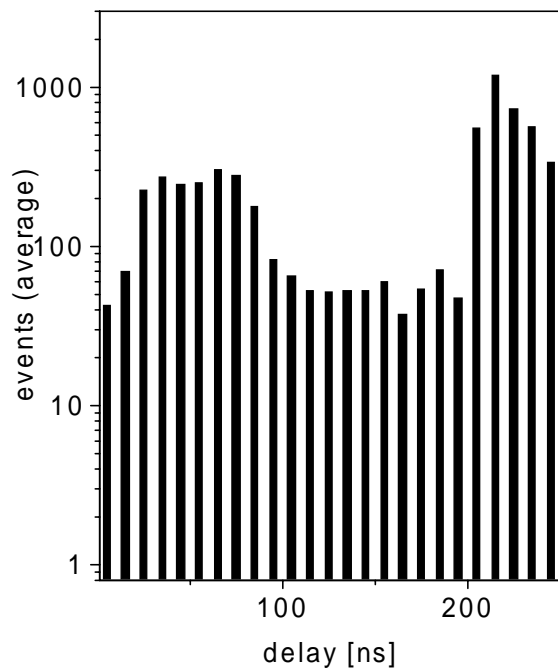


Figure 1: Time distributions of the average of the delayed scintillator pulses.

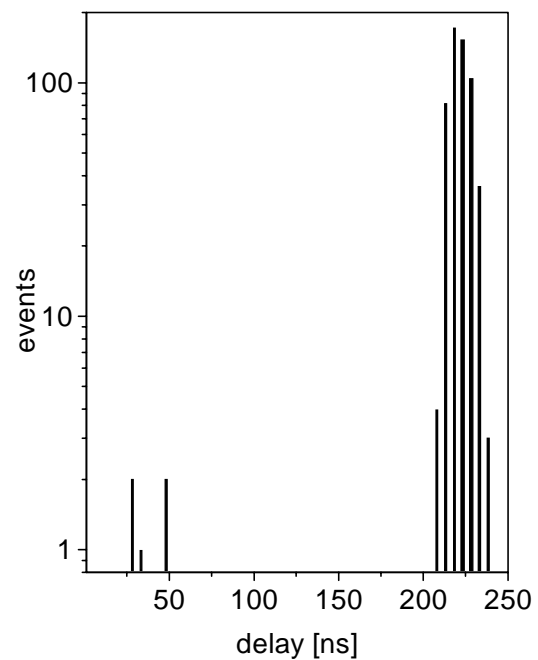


Figure 2: Delay time distributions of triple events.