OG.4.4.07

The Timing Measurement in the Air Shower Experiment in Turku

A.-M. Elo[1], H. Arvela[2]

[1] *Department of Physical Sciences, University of Oulu, FIN-90401 Oulu, Finland*

[2] *Laboratory of Electronics and Information Technology, University of Turku, FIN-20014 Turku, Finland*

Abstract

In the air shower experiment in Turku the shower particle hit times on four fast-timing plastic scintillators are recorded. The data of three detectors are used to determine the direction of the normal of the planar shower front, while the data of the fourth detector is used for verifying the direction. In this paper we study in detail our fast timing measurement system for the determination of the air shower arrival directions.

1 Introduction

In many physical experiments certain results are known beforehand. The examination of these expected results can be utilised in checking the performance of the experimental set-up. The conclusions drawn from these examinations can then be utilised in the further analysis of the data. Our three papers, OG.4.4.07, -08, and -09 in these proceedings, are devoted to the analysis of the timing data obtained in our air shower experiment in Turku.

The air shower array in Turku consisted of scintillation detectors installed symmetrically on the perimeter and in the centre of an approximately 11-meter-radius circle, thus covering an efficient area of 400 m^2. Four pairs of liquid scintillators were used to measure the densities of the electromagnetic component of the air showers (Density Detectors, DD). Four plastic scintillators equipped with fast photo-multipliers detected the arrival times of the shower front (Fast Timing detectors, Fti, i = 1, 2, 3, 4). The central instrument of the array was the hadron spectrometer (HS) which consisted of two over-lapping neutron monitors. The layout of the array is shown in figure 1. A more detailed description of the detector array can be found in Elo et al. (1990) and Elo, \& Arvela (1995).

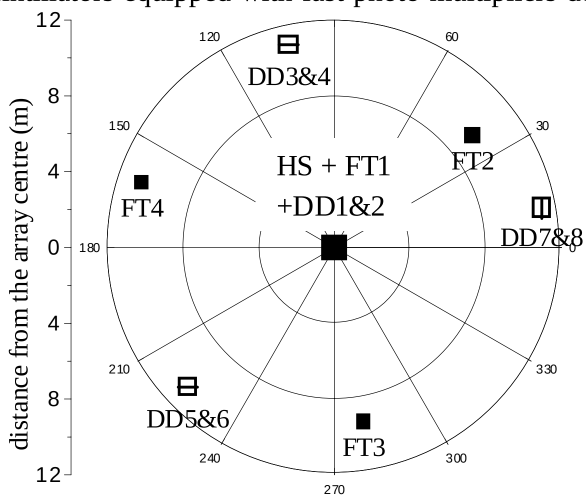

Figure 1: The air shower array in Turku. The labels are explained in the text.

The density data is used in determining the shower size and core location as described by Arvela, Elo, \& Teittinen (1991). The hadron component in the air showers is studied using the multiplicity data recorded with the hadron spectrometer (Arvela, \& Elo 1995a; Arvela, \& Elo 1995b, Arvela 1997). The timing data of the FTi's is used to determine the arrival direction of the air showers and to search for possible delayed sub-shower fronts (Arvela, \& Elo 1995c; paper HE.2.2.29 in these proceedings). The timing measurement and the direction determination procedures were discussed earlier by Teittinen et al. (1991) and Elo and Arvela (1997). In this paper we shall discuss the timing measurement and its results in more detail.

2 The timing measurement

The principle of the measurement arrangement was the following: a four-fold coincidence of the FTi's triggered the read-out of the density information from the DD's and the multiplicity data from the HS. Also the arrival times of the FTi-pulses were recorded relative to the central FT1. All the data, together with event number, time, and date were written on disc of a personal computer. The same PC also controlled the measurement. A detailed diagram of the measurement arrangement was shown in (Elo, \& Arvela 1995).

The details of the measurement system, however, were somewhat changed during the 2-year period that our array was operational. These changes were adjustments and corrections that were found necessary in refining the design the array performance after the beginning of the operation of the array. Also the introduction of new equipment into the measurement required new arrangements. For example the HS-measurement was integrated afterwards into the experiment.

Our original aim was to have on-line analysis of the shower data, but instead of that we ended up in recording the raw data and analysing it later. This order is generally preferable when there are no hindrances concerning for example data storage or telemetry as in e.g. satellite experiments: it allows for making corrections in the data afterwards and/or application of new analysis methods.

3 Comparison of expected and observed timing data

The minimum requirement for determining the air shower arrival direction is the measurement of the hit times of the shower front on three non-collinear detectors. We use the timing data recorded with the outer three FTi's for this purpose as described by Elo, \& Arvela (1997). Then the obtained direction is used to evaluate the hit-time of the shower front on the fourth, central detector, and this 'expectation' value is compared with the observed one. The shower event will be accepted in further analysis if the difference of these two values remains within acceptable error limits.

Application of this procedure was also our first test on the quality of our timing data. We selected from each month's data a sub-set of nearly vertical shower events; i.e. showers with the zenith angles $\theta \leq 5°$, determined using the outer FTi's. Then we evaluated the expectation values of the hit-times on the central FT1. Comparison of these times revealed three separate periods in the measurement, each with different timing separations between the expected and observed hit-times (figure 2). Careful analysis of the measurement timing schemes during these periods gave reliable explanations for each of these differences. Thus they can be corrected for in the actual shower analysis.

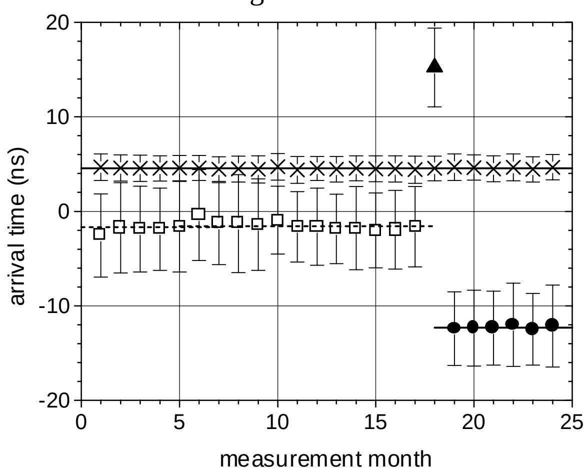

Figure 2: Expected and observed arrival times of shower front on FT1. Lines are best fits to the data.

× expected arrival times

measured times during periods

- □ January 1993 - May 1994
- ▲ June 1994
- ● July 1994 - December 1994

4 Comparison of expected and observed arrival directions

The shapes of the azimuth and zenith angle distributions of the air shower arrival directions are known to be of the forms:

$$(1)\quad \frac{dN}{d\theta} \propto \sin\theta \cos^n \theta \qquad \frac{dN}{d\psi} \propto constant,$$

as discussed in paper OG.4.4.08 in these proceedings. Here the power n is experimentally found to be ~ 8-10. Deviations from these dependencies can be considered as signs of some faults in the experimental set-up, as discussed in paper OG.4.4.09. We used this as another test on the integrity of our timing data.

We evaluated the azimuth direction distributions for each measurement month. Again, we did not find what we expected, i.e. uniform distributions, but instead two different sets of clearly sinusoidally varying distributions. The examination of the (ψ,θ)-distribution of the arrival directions (figure 3a) indicated that the pulses from FT3 were not correctly timed during the later period, but arrived too late compared to the other ones. A similar effect would result if the observation level were tilted from the horizontal plane without taking it into account in the analysis. From figure 3a all showers with $\theta < 25°$ are cut away in order to reduce the size of the plot file. These 11,514 showers are naturally included in figures 3b and 3c.

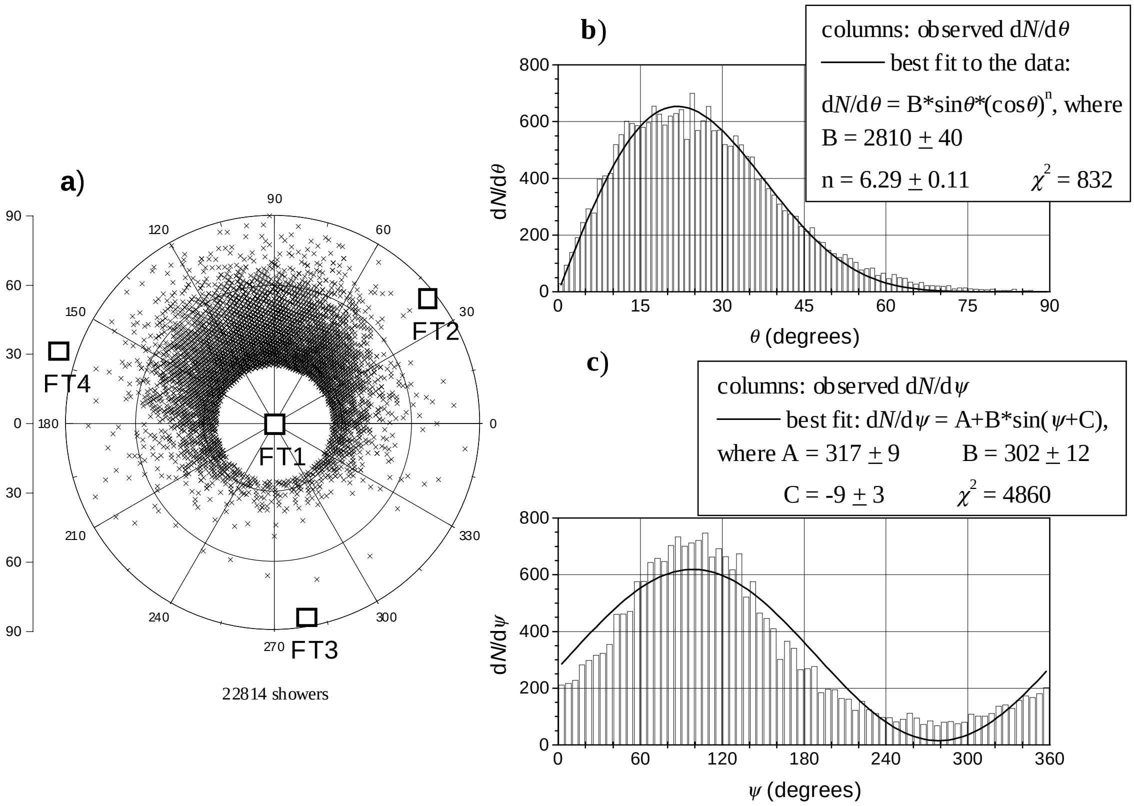

Figure 3: Arrival direction distributions for observed showers without timing corrections.
a) The (ψ,θ)-distribution; **b)** the dN/dθ-distribution; **c)** the dN/dψ-distribution.

Simulations have shown that the arrival direction distributions are deformed exactly in this manner when a systematic timing error is present (compare figure 3 with figure 2 in paper OG.4.4.09). The procedure to find the right correction is described in paper OG.4.4.08. The time-corrected arrival direction distributions for the showers above are also shown in figure 3 in paper OG.4.4.08.

Finally the direction distributions evaluated from simulated data without timing errors are shown in figure 4 for comparison with figure 3 in paper OG.4.4.08. Here for the zenith angle distribution power-index n = 8.89 obtained in OG.4.4.08 was used. From figure 4a all showers with $\theta < 27°$ are cut away in order to reduce the size of the plot file. These 15,562 showers are naturally included in figures 4b and 4c.

As what comes to explaining or finding the cause for these faults discovered in our measurement more scrutiny of the measurement notes is necessary. It may nevertheless well be that we shall never be able to explain them satisfactorily, as the array itself does not exist any more and we cannot reconstruct the

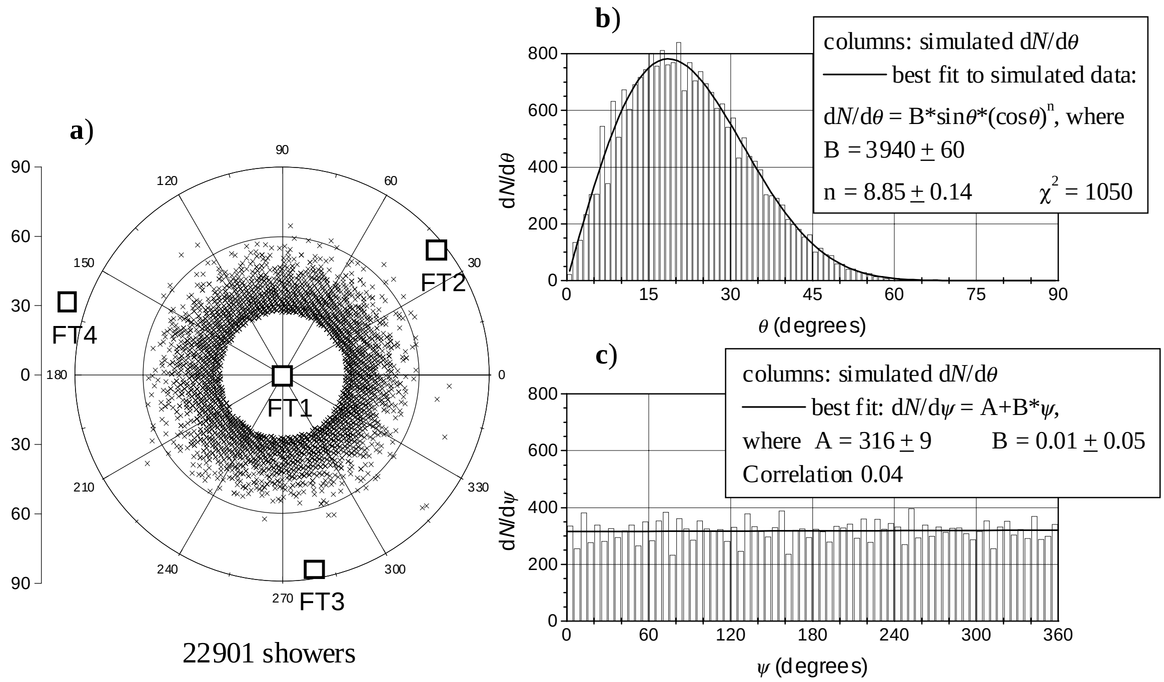

Figure 4: Direction distributions for simulated showers with no timing errors.

measurement hardware. This is not, however, necessary as we can correct these errors afterwards and still use our data in the shower analysis.

5 Conclusions

As conclusions we can make the following remarks. An experiment can never be too carefully designed. One should have enough time or personnel (or both) to evaluate the operation of the measurement apparatus before the actual measurements, or at least early enough during them so that they can be repeated if it turns out to be necessary. One can never make too comprehensive notes of an experiment.

References

Arvela, H., Elo, A.-M., \& Teittinen M., Proc. 22nd ICRC (Dublin, 1991), 4, 448

Arvela, H., \& Elo, A.-M., Proc. 24th ICRC (Roma, 1995a), 1, 332

Arvela, H., \& Elo, A.-M., Proc. 24th ICRC (Roma, 1995b), 1, 336

Arvela, H., \& Elo, A.-M., Proc. 24th ICRC (Roma, 1995c), 1, 340

Arvela, H., A Cosmic-Ray Air Shower Detector: Performance and Data Analysis, Doctoral Thesis, Annales Universitatis Turkuensis, AI 224, 134 pages, 1997 (University of Turku)

Arvela, H., \& Elo, A.-M., Proc. 26th ICRC (Salt Lake City, 1999), paper HE.2.2.29

Elo, A.-M., et al. Proc. 21st ICRC (Adelaide, 1990), 10, 293

Elo, A.-M., \& Arvela, H., Proc. 24th ICRC (Roma, 1995), 1, 344

Elo, A.-M., \& Arvela, H., Proc. 25th ICRC (Durban, 1997), 7, 233

Elo, A.-M., \& Arvela, H., Proc. 26th ICRC (Salt Lake City, 1999a), paper OG 4.4.08

Elo, A.-M., \& Arvela, H., Proc. 26th ICRC (Salt Lake City, 1999b), paper OG 4.4.09

Teittinen M., Arvela, H., \& Elo, A.-M., Proc. 22nd ICRC (Dublin, 1991), 4, 436