OG.4.4.09

The Effect of Timing Inaccuracy on the Shower Arrival Direction

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

The effects of systematic errors on the shower arrival directions have been studied by shower simulations. As results, systematic and characteristic shifts in the arrival directions have been found. The azimuth direction distribution becomes non-uniform so that positive timing error creates a minimum in the distribution in the direction of the erroneous detector, and a maximum in the opposite direction. Negative error reverses the situation. The zenith angles change accordingly. The non-uniformity of the azimuth distribution is thus an indicator of timing errors in the measurement system.

1 Introduction

The air shower front may be assumed to be planar near the shower core. In air shower experiments a fast timing method is often used to determine the arrival direction of air showers on an array of detectors on the ground. In the simplest case, three non-collinear detectors are required to give a unique arrival direction. Usually the detectors are scintillators equipped with fast photomultiplier tubes, and the resulting pulses are recorded with a fast Time-to-Digital Converter, TDC. The relative pulse arrival times are then fitted to a plane, and the arrival direction is then obtained as the normal of this shower plane.

In our previous work (Elo, \& Arvela, 1997) we studied the effects of various error sources on the accuracy of the arrival direction determination. In the calculations we used different values for the errors of the measurement parameters to find their contributions to the absolute maximum error of the directions of individual showers. For example, the area of a scintillation detector is usually at least 0.5m×0.5m, giving a lateral inaccuracy of ± 0.25m in the hit position of the shower particles at the location of the detector. The inaccuracy of the hit position results in an error of about 10 degrees in the zenith angle.

In this paper we specifically study the effects of timing inaccuracies on the air shower arrival direction. Random errors arise from the nature of the shower plane, which actually is not a plane at all, but a more or less sparse collection of discrete, coherent particles, as pointed out for example by Linsley (1995). The shower particles arrive at the detectors within a finite time window of a few nanoseconds. Their longitudinal spread depends on the shower size and the distance from the core. This spread, together with the lateral uncertainties, leads to significant inaccuracy in the arrival direction determined as described above. Even near the core this may become a serious problem especially in the analysis of small air showers with low particle densities. Systematic errors, on the other hand, can be due to any fault in the measurement system, for example incorrectly determined cable lengths or detector locations, just to mention few. In this paper we describe how systematic timing errors can be found.

2 Analysis method

The effects of the timing inaccuracies were studied using shower simulations. First we created a sufficient number of artificial showers with known arrival direction distributions. For obtaining the zenith angles θ we used the expression

$$\frac{dN}{d\theta} = A \sin\theta \cos^n\theta \ , \qquad (1)$$

and for the azimuth angles ψ a uniform distribution

$$\frac{dN}{d\psi} \propto constant \ . \qquad (2)$$

In the zenith angle distribution (1) the constant A depends on the desired total number of showers, and the power index n was taken to be 10 in our calculations.

The next step was to evaluate the hit-times on the detectors for shower fronts incident from the arrival directions obtained in the previous step. After that a desired amount of timing error was introduced, and then artificial shower data with the erroneous timing information were created. Finally, this simulated hit-time data was analysed using our normal shower analysis program. As a result, we obtained the arrival direction distributions corresponding to the introduced timing errors.

3 Results

First we studied how a timing error in one single detector shifts the arrival direction of an individual air shower. It was seen that when the timing pulse is recorded too early (negative error) on any detector Fti (i = 2, 3, 4), the direction of the shower is shifted ‘towards’ this detector. Positive error (pulses arriving too late) moves the arrival direction away from the corresponding detector. Some examples of these are shown in figure 1a in case of erroneous FT2 timing. In these figures the polar angle corresponds to the azimuth angle ψ and the distance from the centre corresponds to the zenith angle θ. The locations of the FT’s are also shown. Their distances on these radial scales are arbitrary. Only their relative azimuth directions are relevant here. Note the different θ-scales on the left and on the right.

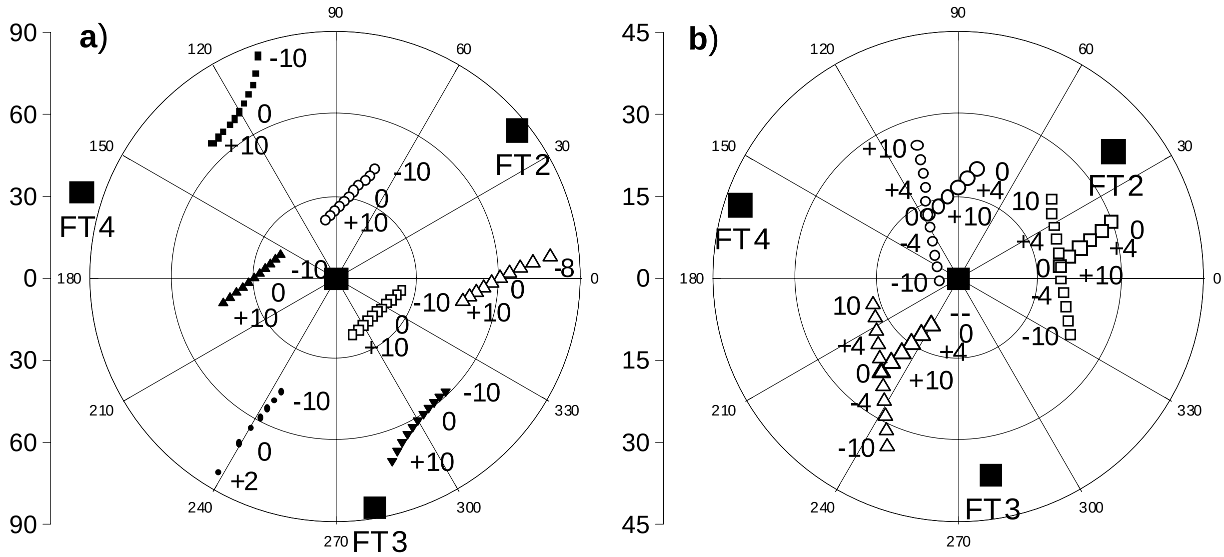

Figure 1: The shifts in the air shower arrival directions as timing error is introduced to the timing of **a)** FT2 (-10 ns to +10 ns); **b)** first FT2 (0 ns to +10 ns) and then to FT3 (-10 ns to +10 ns). Labels indicate the amount of error.

Next we studied how the angular distributions changed when timing errors were added to the data of two detectors. Some examples are shown in figure 1b. Here the larger symbols designate directions obtained when error is first added to one detector, FT2 alone. Then the smaller symbols show how the direction further changes when error is also added to data of another detector, FT3 in this case. As expected on the basis of the results in figure 1a, the final direction is shifted as a ‘vector sum’ of both individual errors.

This can also be seen in the dN/dψ-distribution, where the position of the maximum shifts between the directions of the two erroneous detectors in a way similar to the one shown in figure 2c.

The effect of timing error on the direction distributions of a collection of showers is shown in figure 2. In figure 2a the (ψ,θ)-distribution is shown, displaying an overall shift of arrival directions along the line away from FT3 whose timing was distorted. From this figure all showers with $\theta < 25°$ are cut away in order to reduce the size of the plot file. These 10,722 showers are naturally included in the analyses of figures 2b and 2c. In figure 2b, the zenith angle distribution of showers is evaluated, and fitted to distribution (1), also shown with a dotted line. It can be seen that the mean of the zenith angle, $<\theta>$, becomes larger, and the distribution widens compared to the original one. In figure 2c, the azimuth distribution is shown. The shift in arrival directions twists the originally uniform distribution into a sinusoidal form. The maximum develops in the direction of the detector with erroneous timing or in the opposite direction like here, depending on the sign of the error. Even an error of ±1 ns results in a noticeable deviation from uniformity in the azimuth direction (figure 3). We also found that the amplitude of the fitted sine curve is directly proportional to the magnitude of the error (figure 4). For really large errors, however, this proportionality failed. This is not an actual flaw, as the existence of error will be obvious in the inspection of the azimuth distribution. Besides a suitable correction can be found by trial, as we show in our paper OG.4.4.08 in this conference.

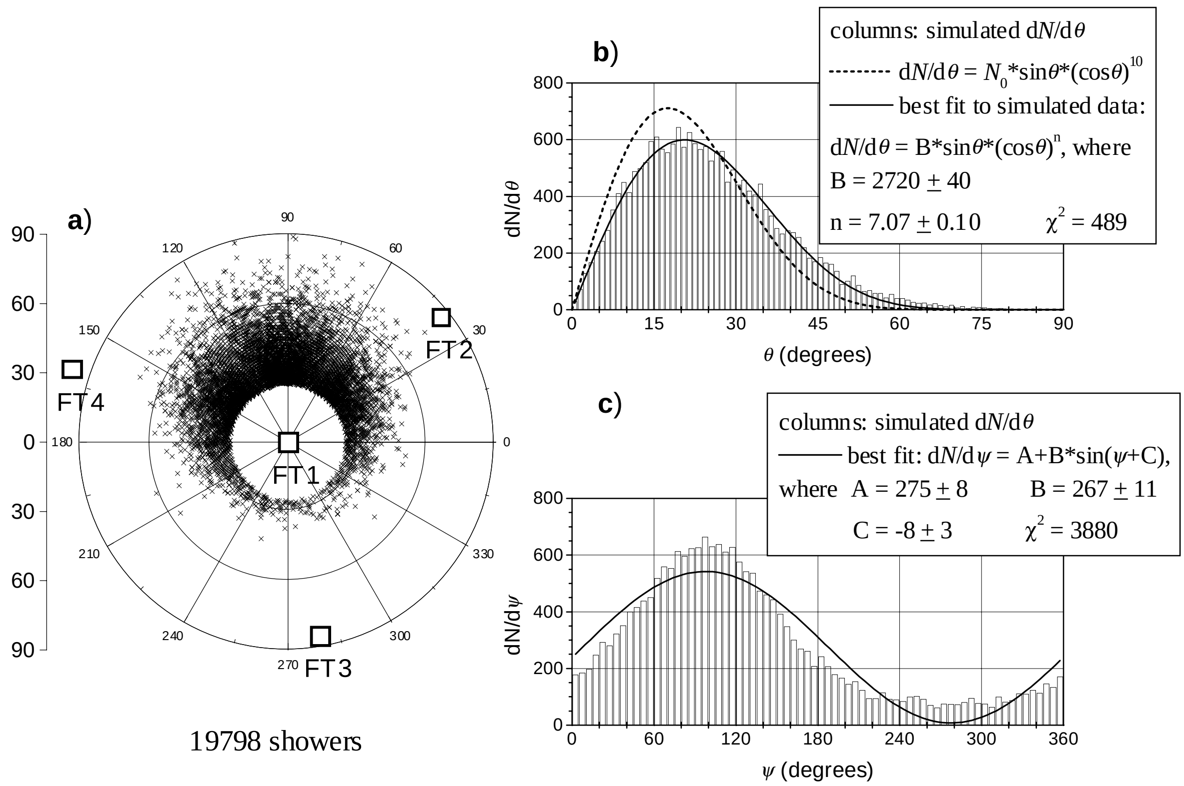

Figure 2: The effect of a timing error of +11.65 ns added in the data of FT3 on a collection of air showers. **a)** The (ψ,θ)-distribution; **b)** the dN/dθ-distribution; **c)** the dN/dψ-distribution.

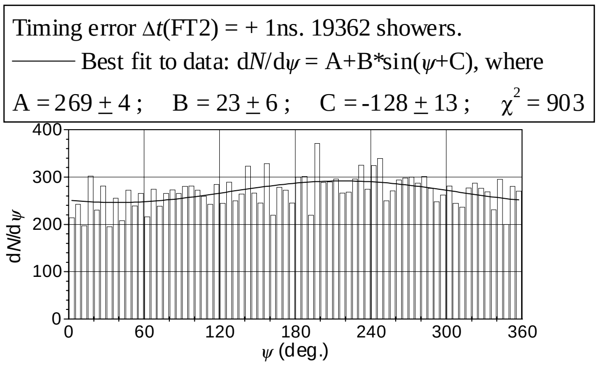

Figure 3: Azimuth direction distribution with timing error +1ns.

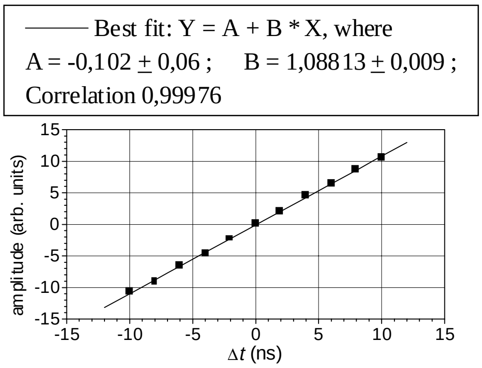

Figure 4: Amplitude of the sine-fit to dN/dψ as a function of timing error.

4 Conclusions

The arrival direction distributions of air showers can be used to verify the correctness of the timing measurement system in an air shower experiment. If the azimuth direction distribution is not uniform the direction of the maximum of the dN/dψ-distribution curve reveals the detector with the erroneous timing. The amplitude of the resulting sine curve is a direct measure of the amount of the error. Errors in the timing of multiple detectors are revealed as well when scrutinising the dN/dψ-distribution of shower arrival directions. The zenith angle distribution, on the other hand, becomes wider as timing error increases, and the average zenith angle grows accordingly.

References

Elo, A.-M. \& Arvela, H., Proc. 25th ICRC (Durban, 1997), 7, 237
Elo, A.-M., \& Arvela, H., Proc. 26th ICRC (Salt Lake City, 1999), paper OG 4.4.08
Linsley, J., Proc. 24th ICRC (Roma, 1995), 1, 354