Procedures and analysis tools for the study of correlations between EEE telescopes

Rev. 1

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Summary:

1. Introduction

This short Report describes the procedures and common analysis tools to carry out correlation analyses of the data originating from EEE telescopes. The aims of such tools are the following:

a) To check raw data from a single EEE telescope, in order to understand the quality of collected data through the relevant variables of interest.
b) To understand possible cuts to apply in the data from each telescope for further correlation data analysis.
c) To check consistency of the GPS data information.
d) To build a time correlated data file from two EEE telescopes in order to search for coincident events within a fixed time window.

The aim is to establish a common procedure between different EEE sites, and describe and distribute a free software, able to analyze time and orientation correlations between EEE telescopes.

In view of its possible use also by high school students and teachers, basic procedures are described in detail, whereas experienced users may likely skip many of the points described in the following.

2. Description of the procedure

The procedure is based on the following steps which are here described. Apart from the first step, based on the standard EEE Analyzer software, the other steps require to execute two macros developed under the framework ROOT. For the users who are not familiar with ROOT, Appendix A gives some basic details on how to install this package from the CERN site.

Step 1: Analyze raw data and create .out files by the standard EEE Analyzer program (this software tool is already existing as a part of the standard EEE software).
Step 2: Create two ROOT tree files with data from each of the two telescopes, by using the macro create_EEEtree.C
Step 3: Correlate the two ROOT tree from the two telescopes and create an output ROOT tree with correlated data, by using the macro correlation_EEE.C
Step 4: Perform correlation analysis on the correlation tree file.

Step 1: Analyze raw data and create .out files by the standard EEE Analyzer program.

Fig.1 shows a typical .out file, as produced by the EEE Analyzer program starting from the binary files collected during acquisition. On an event-by-event basis, the following variables are listed in such file:

- Run Number
- Event Number
- Event time (seconds since January 1st, 2007)
- Event time (nanoseconds)

- Time since start (in microseconds)
- Director cosines (X, Y and Z)
- $\chi 2$ of the track fit
- Time-of-flight (in nanoseconds) between top and bottom chambers
- Track length (in centimeters) between top and bottom chambers

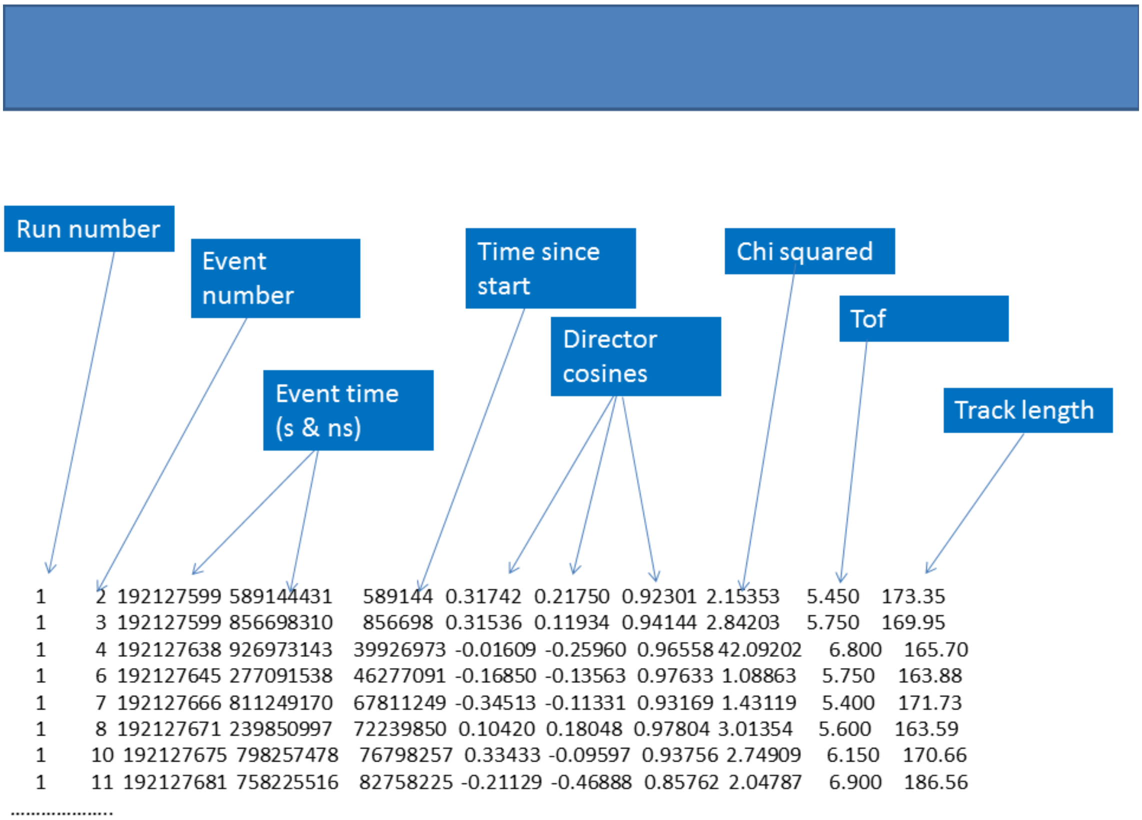

Fig.1: A typical output file produced by the EEE Analyzer.

Starting from version 2.5, the analyzer prints additional variables, such as:

- Hit position (x,y) and time on each chamber
- Intersection (x,y) of the track on each chamber
- Number of hit strips on each chamber
- Number of clusters on each chamber

Step 2: Create two ROOT tree files with data from each of the two telescopes, by using the macro create_EEEtree.C

In this step, a macro is used under the ROOT environment to create a ROOT tree file, which contains the variables of interest for each of the two EEE telescopes, in order to proceed for further correlation analysis. All the data from a day of data taking are analyzed in a single step, so that an output tree file is created which contains the data from a complete day. The macro needs to be executed twice, one for each EEE telescope, replacing the name of the input data file in the configuration file.

Such macro is executed, after opening a ROOT session, by the command:

.x create_EEEtree.C

The user must specify in the configuration file **config_create_EEEtree.txt** the telescope name (unique code, example CT-01, CERN-01,…), day (in the format YYYY-MM-DD) and the path where to search for the .out files. It is assumed that both the macro and the config file stay in the directory C:/root/macros/. The box shows an example of configuration file under Windows:

```
CERN-02

2010-07-15

C:\\CERN-02\\2010-07-15\\out\\
```

The name of the output file mirrors the telescope code and date. Thus, the file CT-01-2012-05-03.root means a file containing all the data collected by the telescope CT-01 on May, 3, 2012. The file is created in the directory specified by the path (3rd line in the config file), which also contains the .out files.

The ROOT tree file which is created by this macro contains event-by-event the following variables:

- *time*: GPS time of the event (seconds + nanoseconds)
- *theta*: Zenithal angle (degrees)
- *phi*: Azimuthal angle (degrees)
- *chi*: $\chi 2$ of the track fit
- *tof*: Time-of-flight between top and bottom chambers (nanoseconds)
- *l*: Track length (centimeters)

In order to avoid unrealistic peaks in the azimuthal angle distribution (due to those events where the same strip number is hit in all chambers, thus leading to an azimuthal angle exactly equal to zero in the chamber reference system), a realistic Gaussian spreading is introduced in the azimuthal angle.

The execution of this macro requires about 100 CPU seconds on a standard notebook, producing a ROOT tree file of about 60 Mb for about 2.5M events, roughly corresponding to a data taking period of 1 day in case of a telescope collecting data at a rate of 30 Hz.

3. Typical results

Once created, the two ROOT tree files should be used to check the data quality from each individual EEE telescope. As an example, a few plots follow, extracted from one day data taking period in one of the EEE telescopes in Catania (CT-01). Figs.2-7 show respectively the $\chi 2$

distribution, the time-of-flight (tof) distribution, the particle speed (given by the ratio between the track length and the time-of-flight), the GPS time distribution, and the zenithal and azimuthal angle distributions.

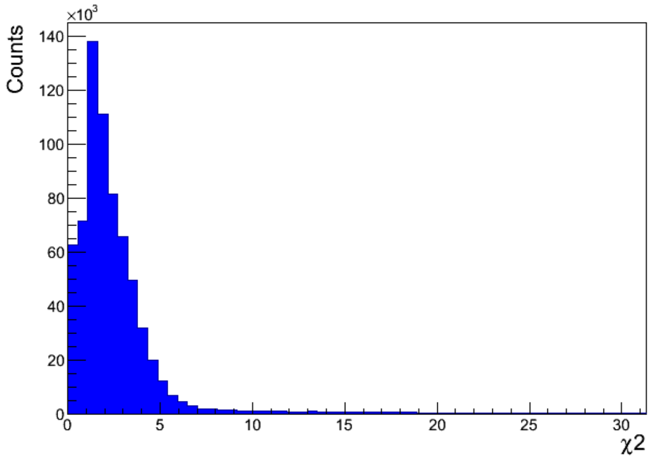

Fig.2: $\chi 2$ distribution.

Each of these plots may be created interactively during a ROOT session, opening the file of interest by the command:

TFile f("C:\\CT-01\\2012-05-03\\out\\CT-01-2012-05-03.root")

and then plotting the distribution of interest by the command:

tree-> Draw("tof")

which produces – as an example – the time-of-flight distribution (see fig.3).

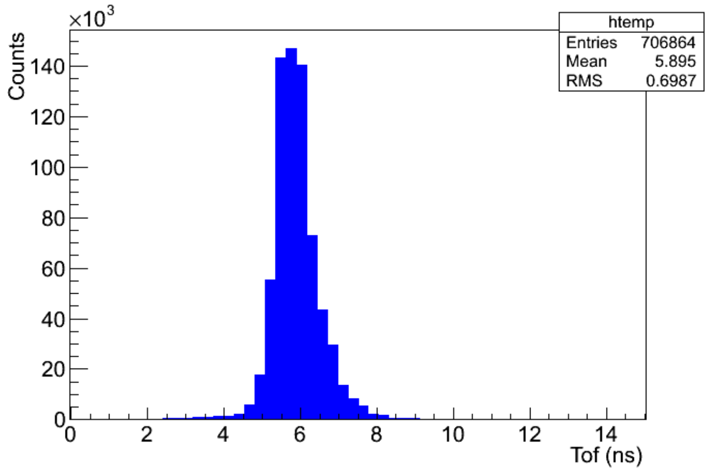

Fig.3: Time-of-flight distribution.

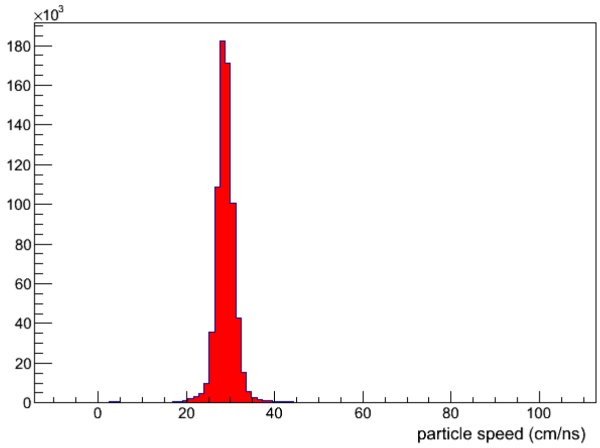

Fig.4: Distribution of the particle speed (ratio between track length and time-of-flight).

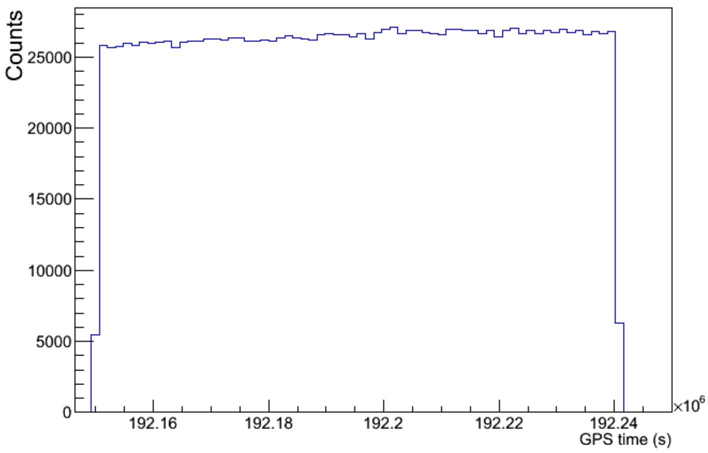

Fig.5: Distribution of the events along the GPS time.

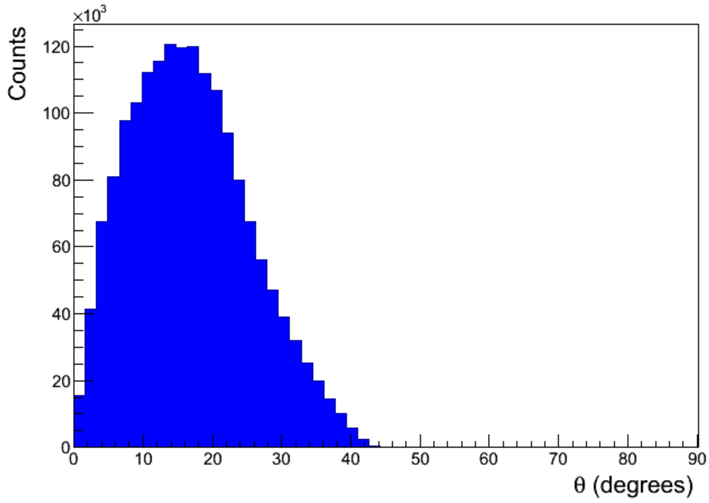

Fig.6: Zenithal angle distribution.

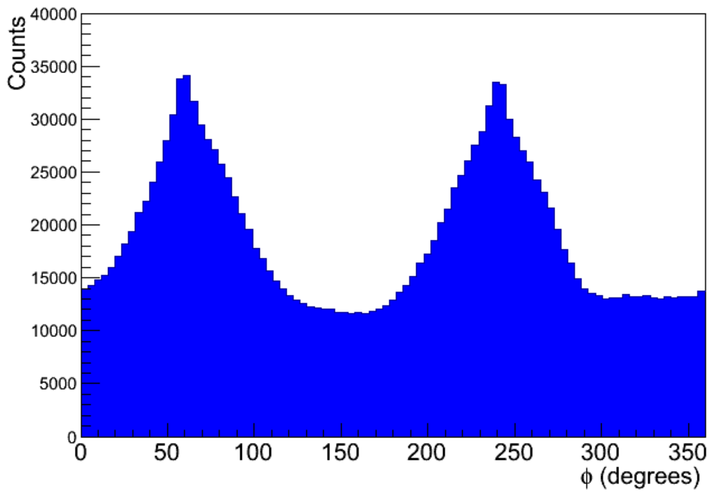

Fig.7: Azimuthal angle distribution.

Step 3: Correlate the two ROOT tree from the two telescopes and create an output ROOT tree with correlated data, by using the macro correlation_EEE.C

The task of this step is to create an output ROOT tree file, which contains information on events which are time correlated in the two EEE telescopes within a user-defined time window. Since each EEE telescope may record a number of events per day of the order of 1-2 x 10^6 (for instance with an acquisition rate of 20 Hz, a telescope would produce about 1.7 million events per day), correlating any event with any other event in a day of data taking would produce a huge number of combinations, in the order of 1M x 1M = 10^{12} combinations. To avoid this, events are classified into sequential time cells and each event from a telescope is correlated only with events from the other telescope belonging to the same, previous or next cell (Fig.8). In such a way, the number of combinations is strongly reduced (by a factor 10^5 – 10^7) to a reasonable amount of combinations and realistic values of file size.

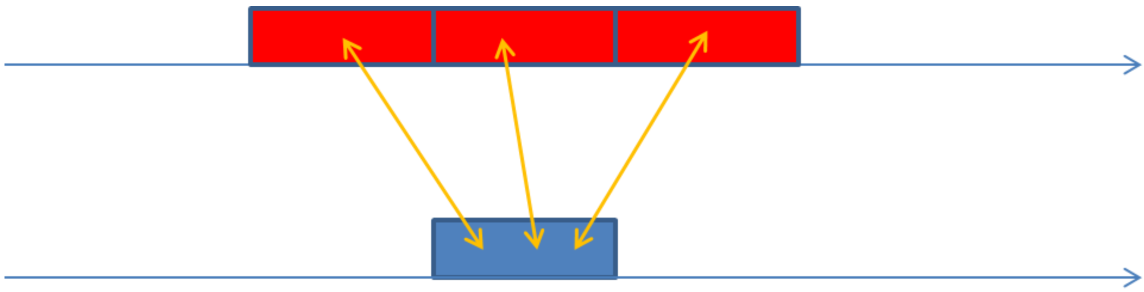

Fig.8: Correlating each event in a given cell from one telescope to the events in the other telescope belonging to the previous, same or next cell.

The choice of the time window determines the number of combinations (no. of entries in the output file), as well as the file size. Fig.9 shows typical values of these quantities for one day of collected data. Taking into account that the distance between the most distant telescopes in the EEE network is presently about 1200 km (CERN-Catania), corresponding to about 4 ms light, a realistic choice for the time window could be ± 10 ms, which is the default value assumed in the macro. The CPU time needed to analyze data from 1 day is about 1 minute CPU on a standard notebook.

After opening a ROOT session, the macro to build the output tree is executed by the command:

.x correlation_EEE.C

The user must specify in the config file (named **config_correlation_EEE.txt**) the two telescope codes, the date, the two paths where to retrieve the ROOT individual telescope data and the path where to produce the correlation tree file. Such configuration file should stay, together with the macro, under the directory C:/root/macros/.

The inset shows an example of this config file:

```
CERN-01

CERN-02

2010-07-15

C:\\CERN-01\\2010-07-15\\out\\

C:\\CERN-02\\2010-07-15\\out\\

C:\\root\\
```

where it is assumed that the two individual ROOT files containing the data from the two telescopes are under the directory where they were produced in the previous step and the output is produced under C:\\root.

In case the user wants to select a different time window (for instance 100 ms instead of 10 ms), the macro will be executed with the command

.x correlation_EEE.C(0.01)

where the value in parenthesis gives the selected time window in seconds.

Time window	No. of cells/day	Size of output tree (1 day)	#Entries (1 day)
1 ms	~ 86 M	~ 30 Mb	~ 450k
10 ms	~ 8.6 M	~ 200 Mb	~ 4.5 M
100 ms	~ 860 k	~ 900 M	~ 25 M

Fig.9: Various choices of the time window to build the correlated ROOT tree file.

The procedure produces a file whose name takes into account the name of the two telescopes and the date. Thus, the name CERN-01-CERN-02-2010-05-03.root means the filename containing the correlated events collected by the telescopes CERN-01 and CERN-02 during May 3, 2010.

The output correlation tree contains the following variables:

- *time1*: GPS time of the event (taken from telescope #1)
- *theta1*: Zenithal angle (degrees) for telescope #1
- *phi1*: Azimuthal angle (degrees) for telescope #1
- *chi1*: $\chi 2$ of the track fit in telescope #1
- *tof1*: Time-of-flight between top and bottom chambers (nanoseconds) for telescope #1
- *l1*: Track length (centimeters) for telescope #1
- *time2*: GPS time of the event (taken from telescope #2)

- *theta2*: Zenithal angle (degrees) for telescope #2
- *phi2*: Azimuthal angle (degrees) for telescope #2
- *chi2*: $\chi 2$ of the track fit in telescope #2
- *tof2*: Time-of-flight between top and bottom chambers (nanoseconds) for telescope #2
- *l2*: Track length (centimeters) for telescope #2
- *diff*: Time difference between event in telescope#1 and in telescope #2 (seconds)
- *tetarel*: Relative angle (degrees) between the two tracks detected in the two telescopes

Once created, the user may analyze the output tree file with correlated events, also imposing different cuts on the variables of interest, if required.

As an example, Fig.10-14 show a few plots of interest for the two EEE telescopes located at CERN (CERN-01 and CERN-02), where the distance is very small (of the order of 15 m).

Figs. 10-12 show three views of the time difference distribution, in a time window of ± 10 ms, 1 ms and 10 μs respectively, showing evidence of a time peak close to diff=0.

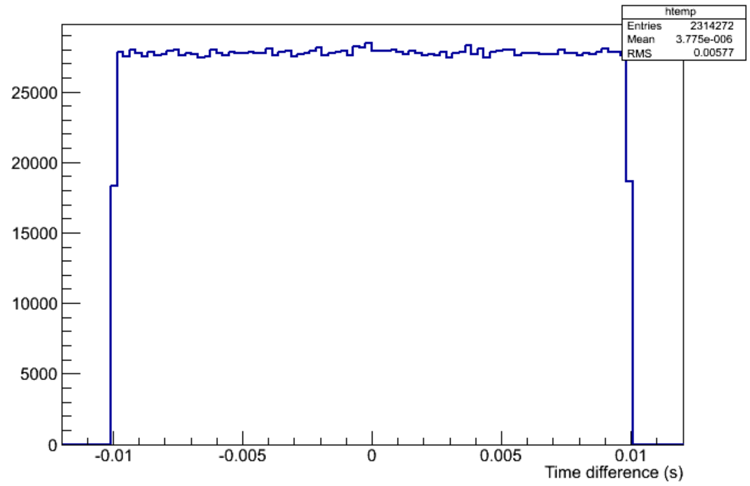

Fig.10: Time difference distribution, in a time window of ± 10 ms.

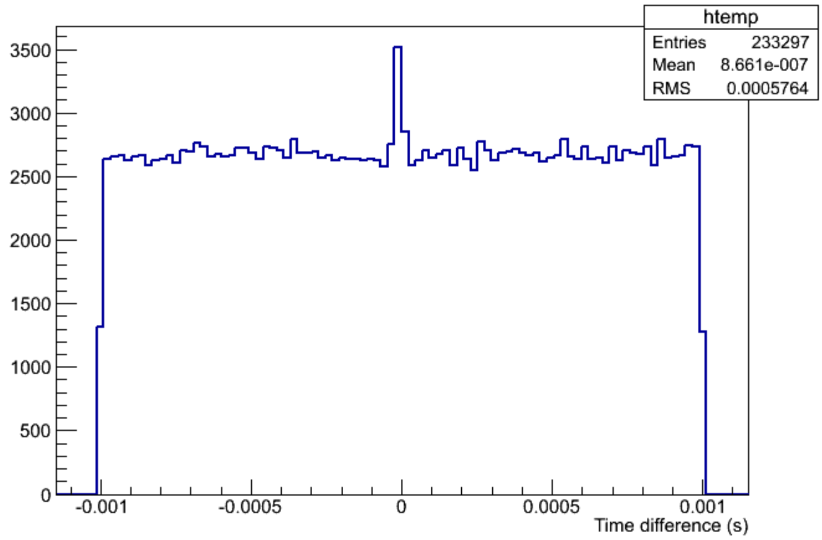

Fig.11: Time difference distribution, in a time window of ± 1 ms.

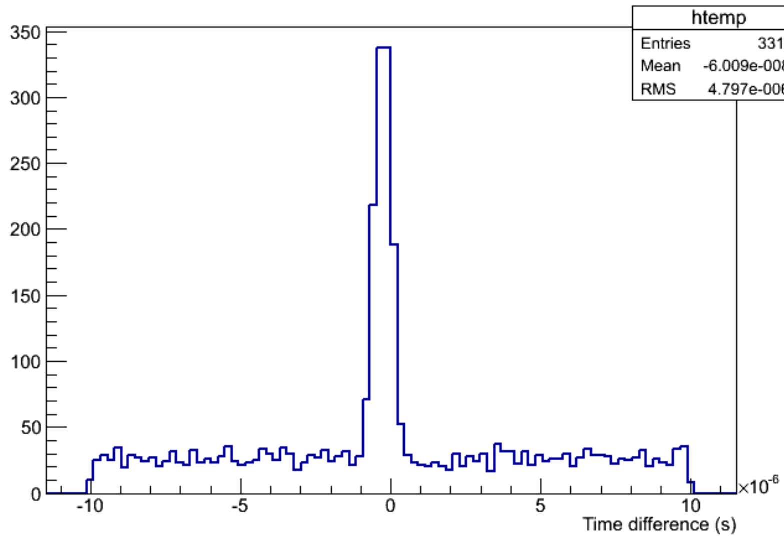

Fig.12: Time difference distribution, in a time window of ± 10 µs.

Fig.13 shows the relative angle distribution,where the relative angle is defined as:

$$\cos\theta_{rel} = \cos\theta_1 \cos\theta_2 + \sin\theta_1 \sin\theta_2 \cos(\varphi_2 - \varphi_1)$$

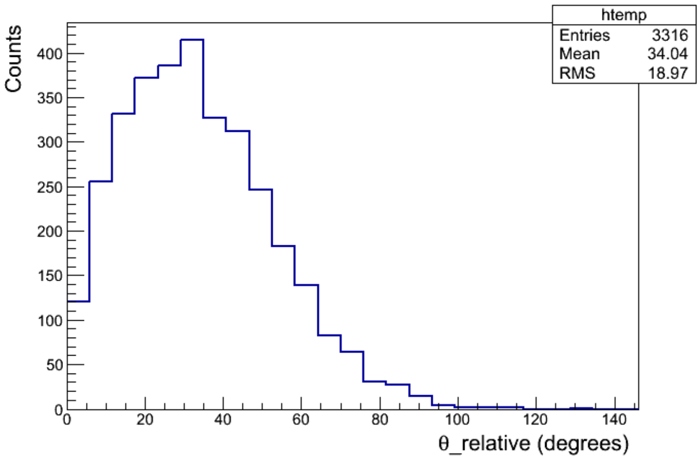

Fig.13: Relative angle distribution.

Fig.14 shows a two-dimensional scatter plot of the time difference versus the relative angle.

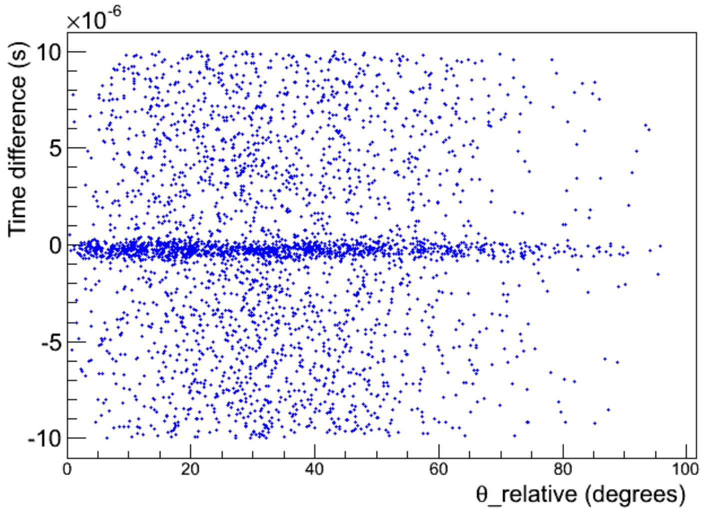

Fig.14: Scatter plot of the time difference between events measured in two telescopes and their relative angle.

4. Appendix A: Installing ROOT

ROOT is a widely used framework in the nuclear and particle physics community. Developed at CERN and freely distributed, ROOT allows a variety of analysis and simulations to be carried out. The starting address for this package is the following:

http://root.cern.ch/drupal/

Several ROOT versions are available, for different operating systems, including Windows and Linux. Most of the examples reported here employed the Version 5.34.03. A large documentation exists on the above mentioned site, covering virtually all the aspects for which ROOT has been created. Its use is recommended also to school students and teacher to carry out simple analysis of the collected data, as well as producing graphical results in an elegant format.

5. Appendix B: Applying cuts to the data

In the previous plots no cuts were applied to the data. The user may apply any combination of mathematical and logical cuts to the data in the correlation tree, following the ROOT syntax. Here follows a simple list of ROOT commands to plot the distribution of the time difference under different cuts.

ROOT command	Description
tree->Draw(“diff”,”abs(diff)<0.0001”)	Plot the variable “diff” within a time window of 100 microseconds
tree->Draw(“diff”,”abs(diff)<0.00001&& tetarel<25”)	Plot the variable “diff” within a time window of 10 microseconds, under the condition tetarel<25 degrees.
tree->Draw(“diff”,”abs(diff)<0.00001&& chi1<20 && chi2<20”)	Plot the variable “diff” within a time window of 10 microseconds for those events where the χ2 is smaller than 20 in both telescopes.
tree->Draw(“diff:tetarel”,”abs(diff)<0.00001&& tetarel<25”)	Produce the scatter plot of the time difference versus the relative angle, for those events having a time difference smaller than 10 microseconds and a relative angle smaller than 25 degrees.