Description of the event reconstruction procedures for the EEE telescopes

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Summary:

1. Introduction

This Report describes the reconstruction procedure for the EEE telescopes and the associated software tools to process the collected experimental data.

Each EEE telescope is made by three MRPC chambers, located at some vertical distance between them. Each chamber may provide the position information (X,Y) of the passage of particles, so that the correlation between the positions in the three chambers allows to reconstruct the muon track and its orientation, together with various parameters of help to characterize the event (time-of-flight, track length, quality of fit,…).

During acquisition, the EEE software produces raw data (binary files, with extension .bin), such as for instance

CT-01-2014-04-25-00001.bin

which according to the EEE notation, means run00001 collected by the telescope CT-01 on April 25, 2014. The size of such binary files may vary by a large amount, depending on the number of events chosen in the acquisition window and on possible acquisition errors, which produce the closing of the current file and the opening of a new one.

For instance, with a number of events per run equal to 100000, typical size of each binary file is about 15 Mbytes. At an acquisition rate of 20 Hz, this corresponds to about 1h20' collection time, so that typically 15-20 files per day are produced. In different EEE installations however, the number of events per run could be smaller, which results in a correspondingly larger number of files being collected each day.

The task of the reconstruction software is to process the raw data (binary files) in order to produce a collection of information on an event-by-event basis. Such task is accomplished by analyzing all the binary files collected in a complete day of data taking.

2. Reconstruction procedure

When a trigger occurs, i.e. when there is a six-fold coincidence between the left and right outputs of the front-end cards, the event is collected, producing on the binary file the list of the strips (channels) involved in that particular event, together with the corresponding TDC information and the GPS time tagging.

A strip which has fired, with the correct TDC channel and TDC time, is considered as a hit. A hit in a chamber is then defined as a strip giving a signal at the two ends, with a TDC value within the limits imposed by the dynamical time range, hence corresponding to a position within the geometrical size of the chamber. The number of hits in each chamber is evaluated (multiplicity), together with the overall hits multiplicity. Fig.1 shows an example of a typical hit multiplicity distribution in one of the MRPC chamber, extracted from a summary file for the CT-01 telescope (100 kevents).

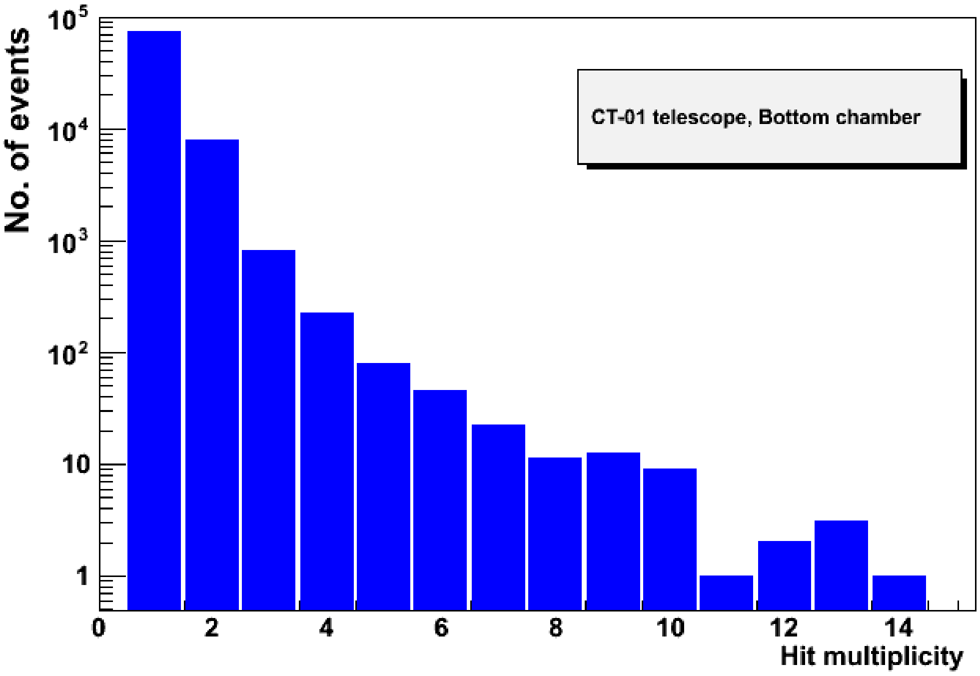

Fig.1: Hit multiplicity in one of the MRPC chambers of the EEE CT-01 telescope.

As it can be seen from Fig.1, the large majority of events have in this case a single hit in the chamber, with about 10% of the events exhibiting two hits. In most of these events with two hits, they belong to a single cluster, since the two hits are close each other.

Similar plots may be obtained also for the middle and the top chambers. The overall hit multiplicity (given by the sum of the hits in all three chambers) is shown in Fig.2. Of course in this case the most part of the events have an overall hit multiplicity of 3, with a fraction of events (a few percent) where no good hits are found in one of the three chambers (thus giving an overall hit multiplicity of 2) and slightly more than 10% of the events with 4 hits (which means one of the three chambers with 2 hits.

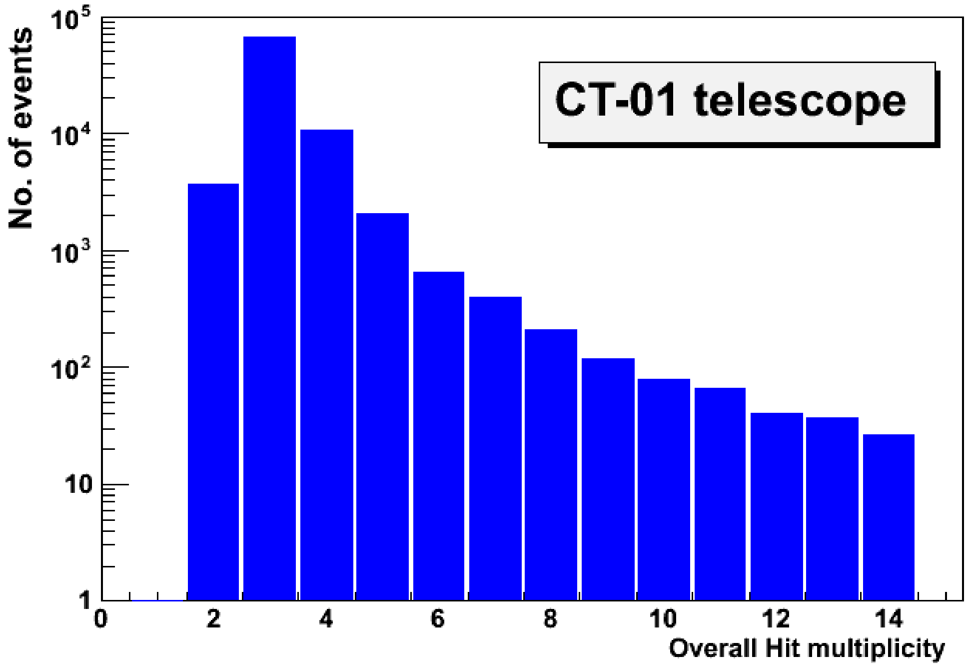

Fig.2: Overall hit multiplicity in the three MRPC chambers of the EEE CT-01 telescope.

We here recall that each MRPC chamber is segmented along one direction into 24 strips, each 2.5 cm wide, with a spacing of 0.7 cm between strips (hence a strip pitch of 3.2 cm). The strip information allows to evaluate one of the two direction (X-coordinate), with a resolution typical of segmented detectors, i.e. 2.5 cm/√12 = 0.7 cm. Along the other direction (Y-coordinate), the position is reconstructed according to the time difference, as measured by the TDCs, between the signals travelling along the strip towards the right and left ends. The channel width of the TDC being 100 ps, and the time range along the strip, due to the signal speed, being ±10 ns, the position along the overall length of the chamber (158 cm) may be measured with a resolution of (100 ps/20 ns)*158 cm = 0.8 cm. Y-coordinate is perpendicular to strip direction (Y=0 for strip 1, Y=82 for strip 24). The X-coordinate is along the strip direction and obtained from the time-difference proportional to (T_left-T_right) which goes from -10 ns to +10 ns.

The reconstruction procedure basically starts from chamber hits, then groups hits into clusters, and finally combines clusters to reconstruct and fit tracks.

After reconstructing hits in the three chambers, reconstruction of cluster points takes place, since the passage of a charged track in the chambers may produce signals on close strips. Cluster points are defined as close hits which satisfy the above mentioned criteria. When two close hits are found, they are merged into a single cluster, whose X,Y-coordinates are evaluated as the average of the two concurrent hits.

Figs. 3 and 4 show the cluster multiplicity distribution in a single chamber (Fig.3) and the overall cluster multiplicity (Fig.4).

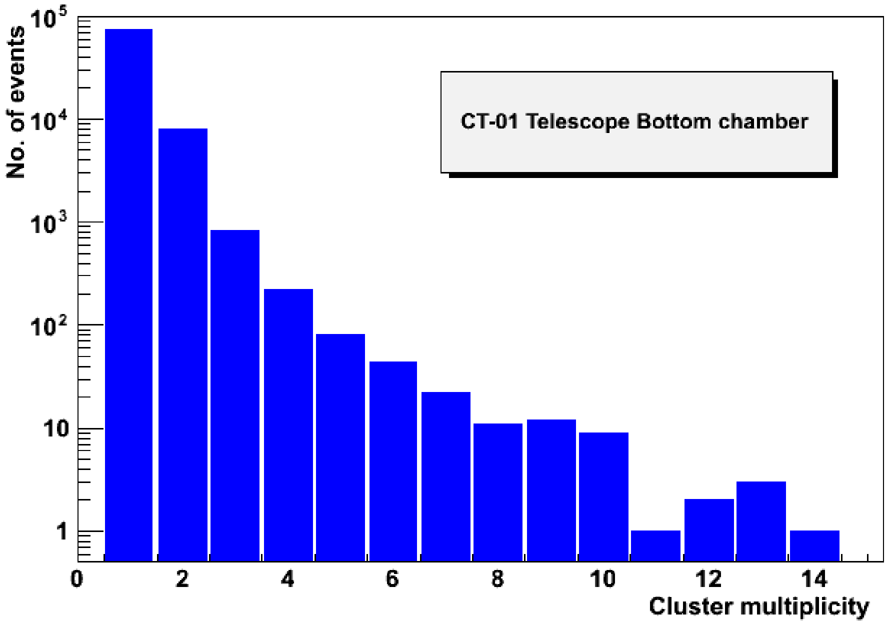

Fig.3: Cluster multiplicity in one of the three MRPC chambers of the EEE CT-01 telescope.

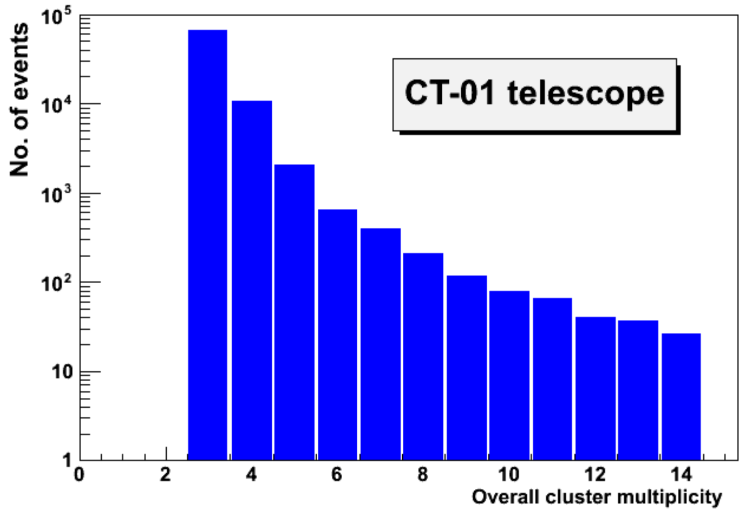

Fig.4: Overall cluster multiplicity in the MRPC chambers of the EEE CT-01 telescope.

When only a cluster point is found in each chamber, track reconstruction is performed by a straight line fit in 3D (both ZY and ZX planes) of the three cluster points and a quality fit parameter $\chi2$ is evaluated. Association of cluster points to a track allows also to evaluate the track length – defined as the distance between the cluster point in the top chamber and the corresponding point in the bottom chamber – and the time-of-flight between such points, evaluated by the TDC information. It is important that the signals from the top and bottom chambers go through the Amphenol cables to the same TDC unit. Moreover, also the director cosines cx, cy, cz are evaluated, from which the zenithal and azimuthal angles Θ and Φ may be extracted, by the following relations:

$$\Theta = \cos^{-1} (cz)$$

$$\Phi = \tan^{-1} (cy/cx)$$

with the usual corrections to take into account trigonometric ambiguities on the azimuthal angle.

In case more than one cluster is found in a chamber, cluster combinations are considered and that having the smallest $\chi2$ is selected. As an example, Fig.5 shows a typical $\chi2$ distribution for a set of events measured in the EEE telescope.

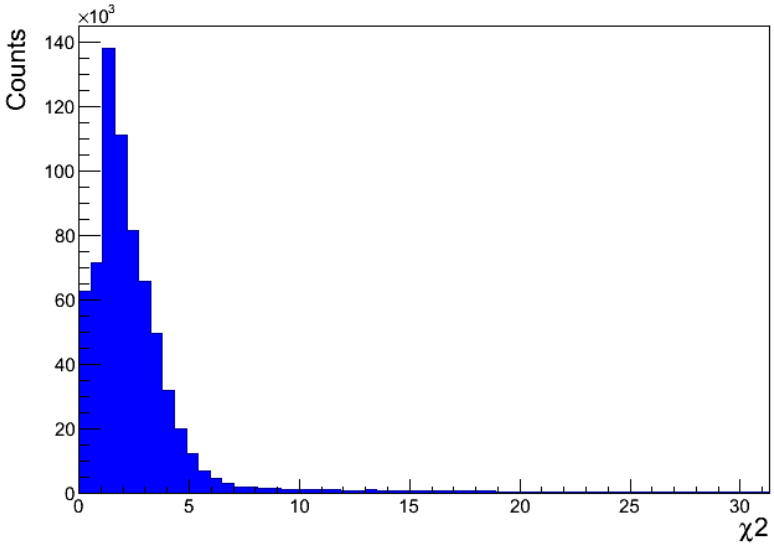

Fig.5: $\chi 2$ distribution of single track fit in the MRPC chambers.

A typical time-of-flight (tof) distribution for the same telescope (distance between top and bottom chambers equal to 80 cm) is shown in Fig.6.

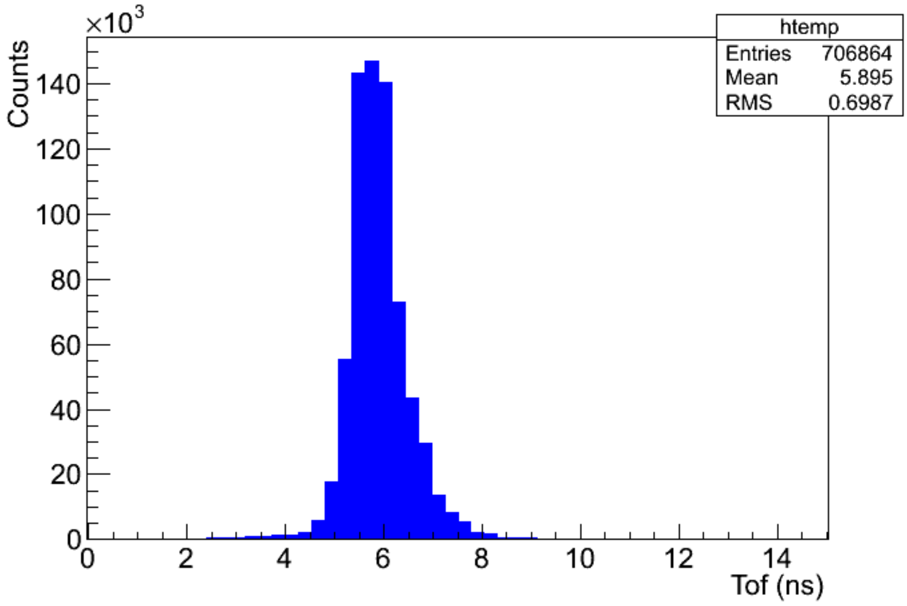

Fig.6: Time-of-flight distribution of single tracks in the MRPC chambers.

The ratio between the track length and the time-of-flight may be used to evaluate the muon “speed” distribution, as shown in Fig.7.

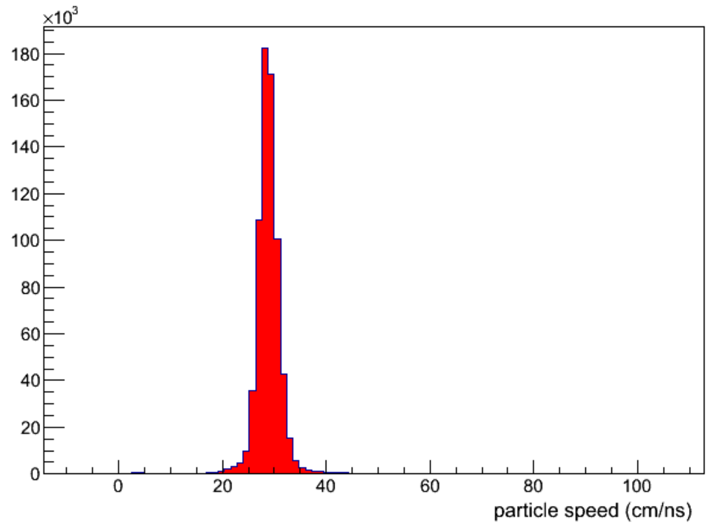

Fig.7: Distribution of the ratio between track length and time-of-flight of single tracks in the MRPC chambers.

The orientation of the muon track is defined by the polar and azimuthal angles. The polar angle distribution follows, to a first approximation, a distribution $dN/d\theta = \sin\theta \cos^2 \theta$, whereas the azimuthal angle distribution should be uniform, apart from absorption effects in the surrounding building and very small physical anisotropies (for instance the East-West effect).

The measured distributions are however affected by the acceptance effects in the EEE telescopes. As a result, the azimuthal angle distribution reflects the rectangular geometry of the telescope, with peaks along the angles corresponding to the long sides of the chambers. As an example, Figs.8 and 9 show the polar (Fig.8) and azimuthal (Fig.9) distributions.

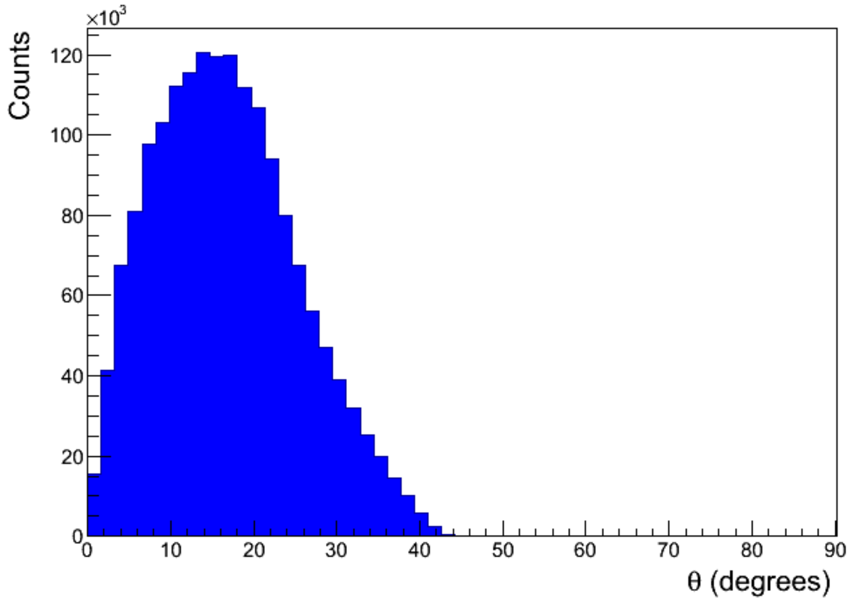

Fig.8: Polar angle distribution of muons reconstructed in one of the EEE telescopes.

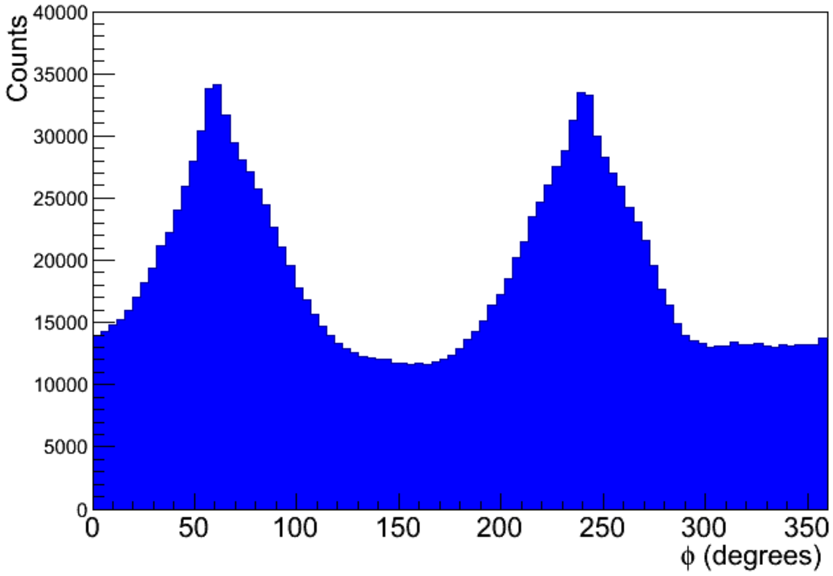

Fig.9: Azimuthal angle distribution of the muons. Peaks around 60 and 240 degrees are due to the rectangular geometry of the chambers and their orientation w.r.t. North.

In case two good individual tracks may be reconstructed, due to the simultaneous presence of two separated cluster points in each of the three chambers, such events are stored in a separate file (with extension ".2tt"), which contains the corresponding information for the two individual tracks.

At the end of the reconstruction process for the overall run, a summary of information is produced (.sum file), which contains statistical information on the hit and cluster multiplicity distributions.

3. Available versions of the software and tests under different operating systems and machines

Each time the reconstruction process takes place, an input file named *eee_calib.txt* is used by the process. This file is used to try to find and align the time difference to the physical lengths of the strips. The first time the program is run, no information comes from this file; after each run the program updates the calibration file. Since the script is usually employed to analyze data from a whole directory (data from one day of data taking), the program must be run twice on the first file at the beginning: the first time to create the calibration file, and the second time to analyze all events with these calibration constants. All subsequent files are just analyzed only once, since the *calib.txt* file already has been created. There is an additional hint concerning the use of such calibration file: when using a new version of the EEE_Analyzer, the old calib.txt file should be deleted, and a new one must be created.

The reconstruction code is usually launched by means of the EEE_Analyzer program, running under Labview, which is part of the EEE official software distribution.

Extensive tests are in progress to check the performance of the reconstruction procedure under different operating systems (Windows, Linux,..) and machines. A summary of these results will be reported in a specific Report.

4. Summary of output files produced during reconstruction

Several ouput files are produced by the software in the reconstruction process:

1. .out files: These are the complete output files, which contain, event-by-event, several information on the reconstructed muon track and the associated GPS time. The size of such files is of the order of 15 Mb for 100kevents.

2. .tim files: These files contain only the GPS time of each reconstructed event.

3. .2tt files: These files contain the information concerning only events where two simultaneous tracks have been reconstructed. The size of such file depends on the fraction of events which have two reconstructed tracks. This in turn depends on various factors, including the chamber efficiency. Typical values of this fraction are of the order of a few percent.

4. .sum files: These are text summary files, containing global information on the file being analyzed.