Analysis and paper on chamber and telescope performance

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(many thanks to F. Noferini and F. Coccetti)

Status

- ✓ spatial and time resolution measured ($\sigma_x \sim 1$cm, $\sigma_y \sim 1$cm, $\sigma_t < 200$ ps)

- ✓ time slewing correction applied (~ 20% improvement on σ_t)

- ✓ trending of several quantities done for a few telescopes
  - ➢ χ^2 and fraction of events with good tracks
  - ➢ fraction of events with aligned hits
  - ➢ time of flight
  - ➢ chamber and telescope multiplicity
  - ➢ HV
  - ➢ trigger rate (duty cycle)
  - ➢ …..
- ✓ efficiency has been measured (with internal and external trigger)

- ✓ writing almost finalized

Time resolution

✓ no selection on events w/o clusters

✓ cut on reconstructed tracks $\chi^2 < 10$

✓ strip by strip calibration applied

✓ result obtained on TORI-03 for Run 2 (same clock distributed to both TDCs) and almost all telescopes in Run 3

✓ preliminary results presented at a few conferences

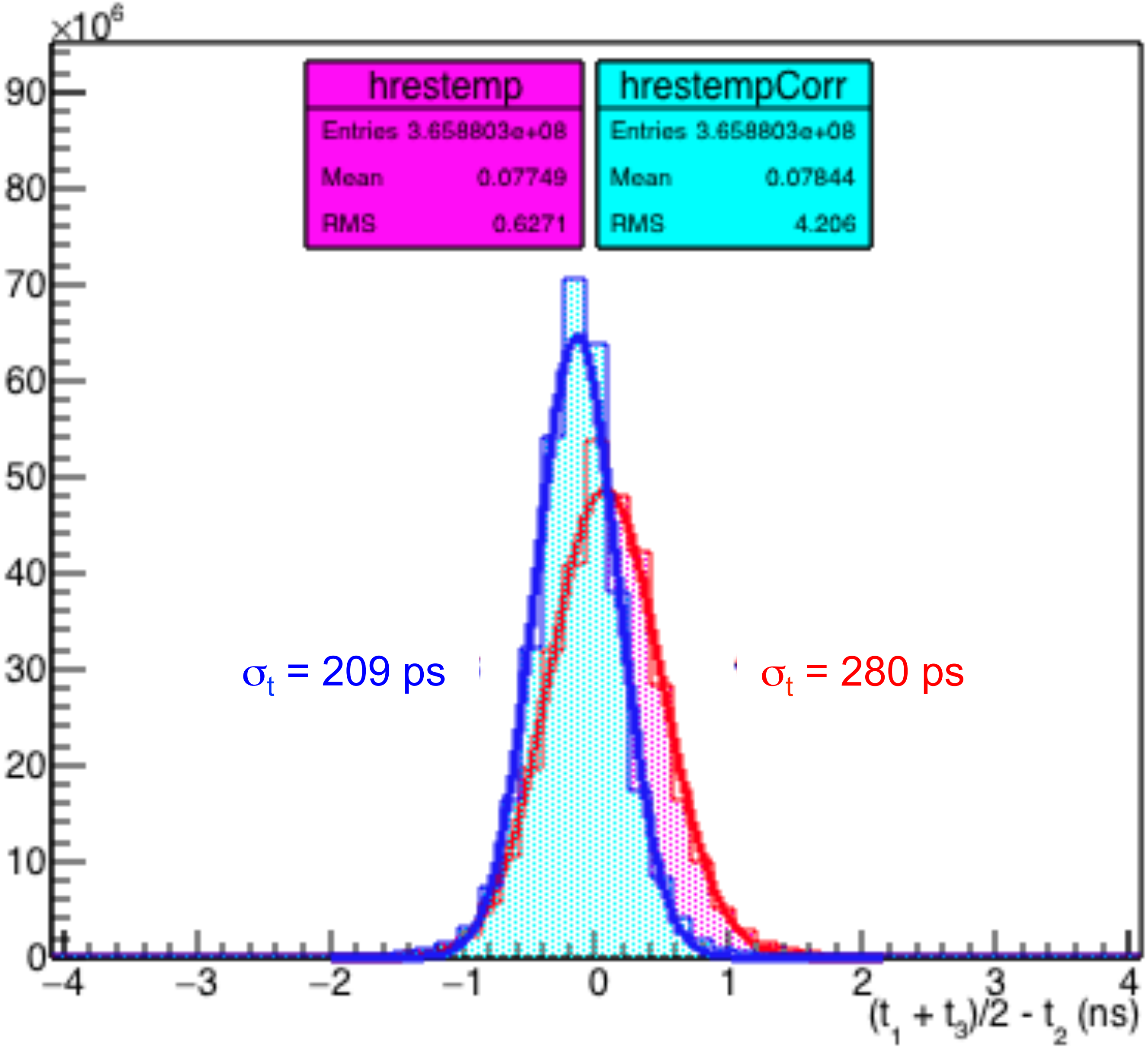
✓ distribution used to measure $\sigma_t = \sqrt{3}/2\sigma_{\Delta T}$

✓ $\Delta T_{hit} = (T_{H\_bot} + T_{H\_top})/2 - T_{H\_mid}$

expected time
on the middle chamber

hit time measured
on the middle chamber

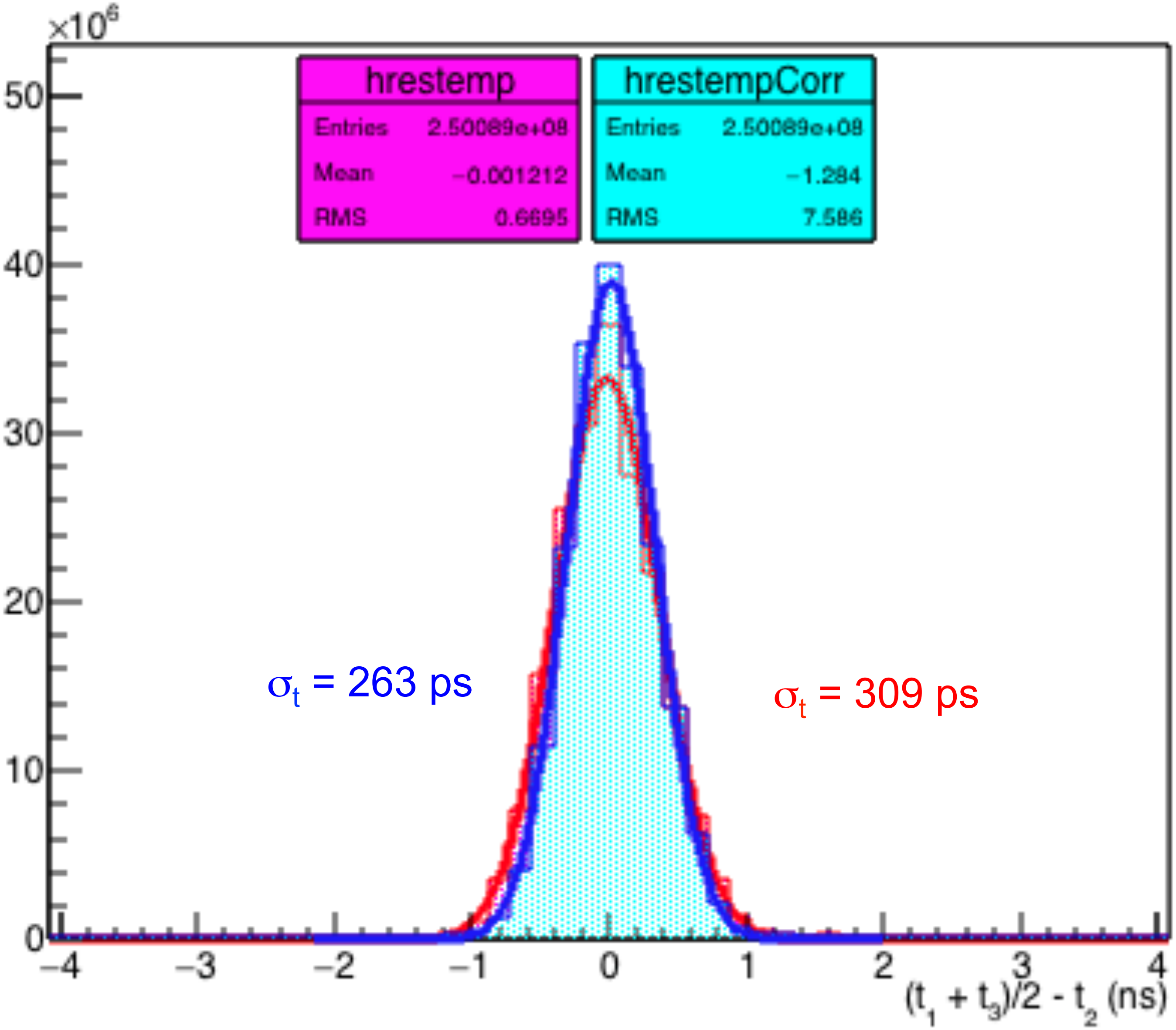
BOLO-01



σ_t = 209 ps

σ_t = 280 ps

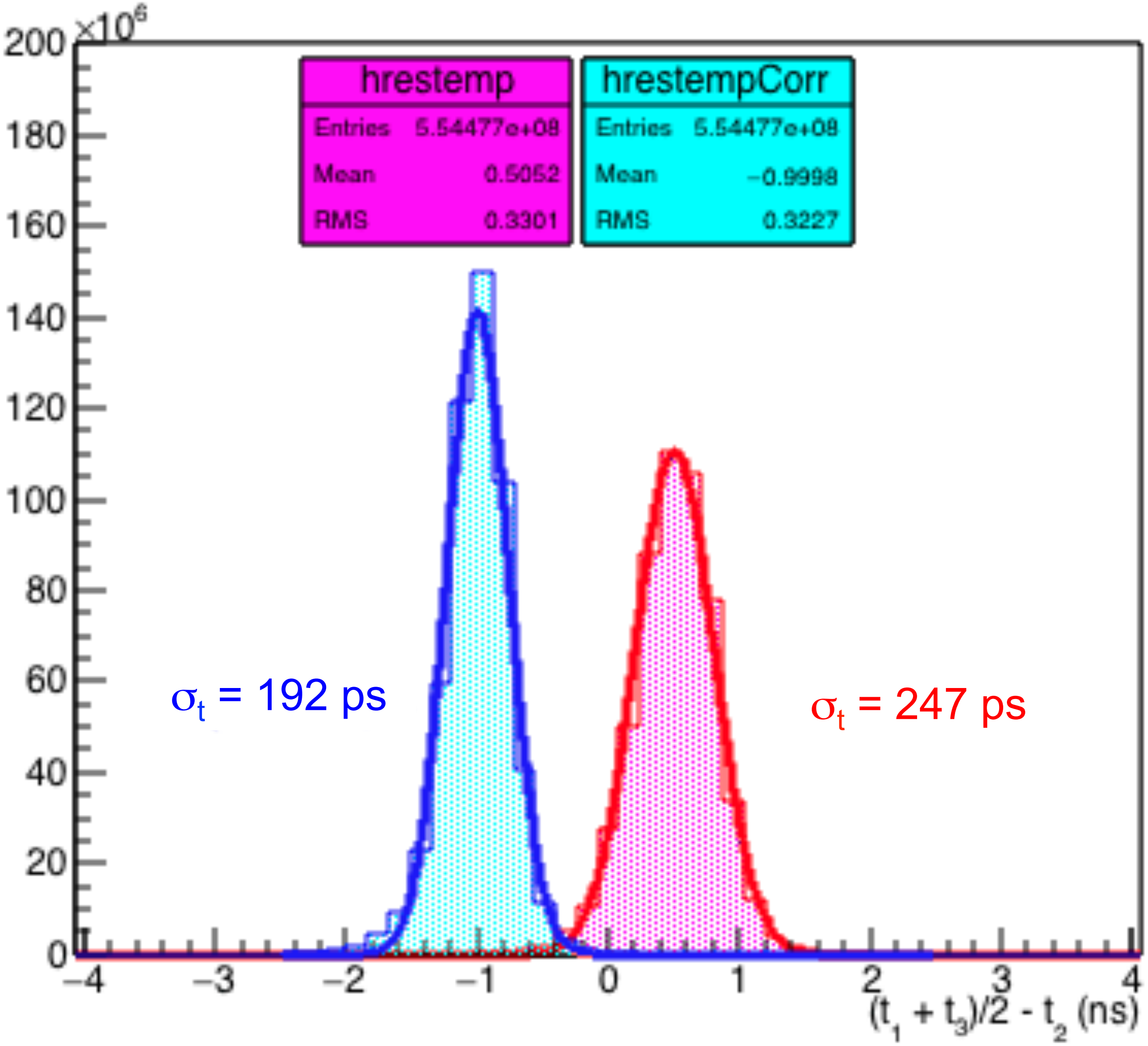
BARI-01



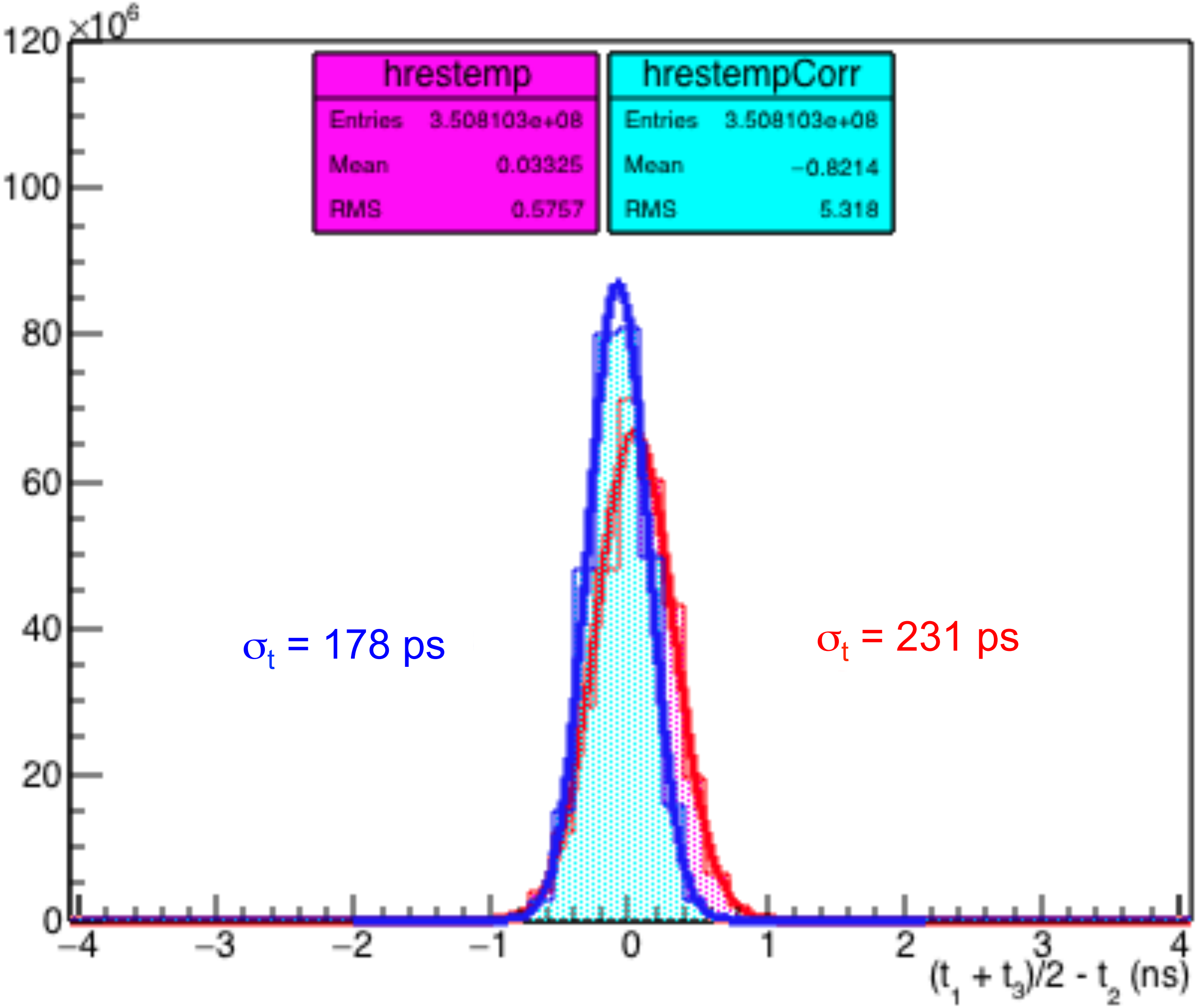
σ_t = 263 ps

σ_t = 309 ps

TORI-01


×10^6
200
180
160
140
120
100
80
60
40
20
0
hrestemp
Entries 5.54477e+08
Mean 0.5052
RMS 0.3301
hrestempCorr
Entries 5.54477e+08
Mean −0.9998
RMS 0.3227
σt = 192 ps
σt = 247 ps
−4
−3
−2
−1
0
1
2
3
4
(t1 + t3)/2 - t2 (ns)

BOLO-03



σ_t = 178 ps

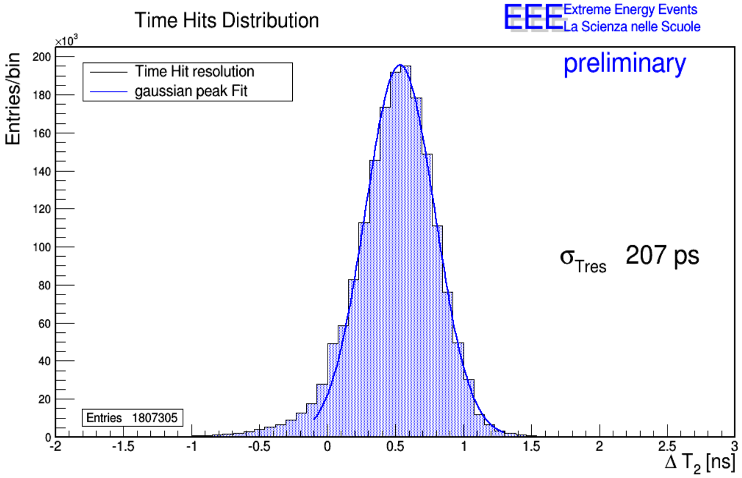
σ_t = 231 ps

Time resolution

✓ time slewing improves time res of about 20%

✓ offsets to be understood (lenght of cable of the middle chamber to be cheked)

ALTA01 offset
BOLO02 small offset
BOLO04 small offset
CAGL01 small offset
CERN01 small offset
GROS01 small offset
LAQU01 small offset
LECC01 small offset
LECC02 small offset
LODI01 small offset
LODI02 small offset
PATE01 small offset
PISA01 offset
SAVO03 small offset
TERA01 small offset
TORI01 offset
TORI03 small offset
TRAP01 small offset
VIAR01 offset



TORI-03 Run 2
to be done in Run 3

✓ σ_t *already in the paper (including comparison with beam tests in 2006)*

✓ results from almost all telescopes available in Run 2 and Run 3

✓ plot showing time resolution for all available telescopes will be included in the paper

Spatial resolution

✓ no selection on events w/o clusters

✓ cut on reconstructed tracks $\chi^2 < 10$

✓ strip by strip calibration applied

✓ result obtained on TORI-03 for Run 2(same clock distributed to both TDCs) and almost all telescopes in Run 3

✓ preliminary results presented at a few conferences

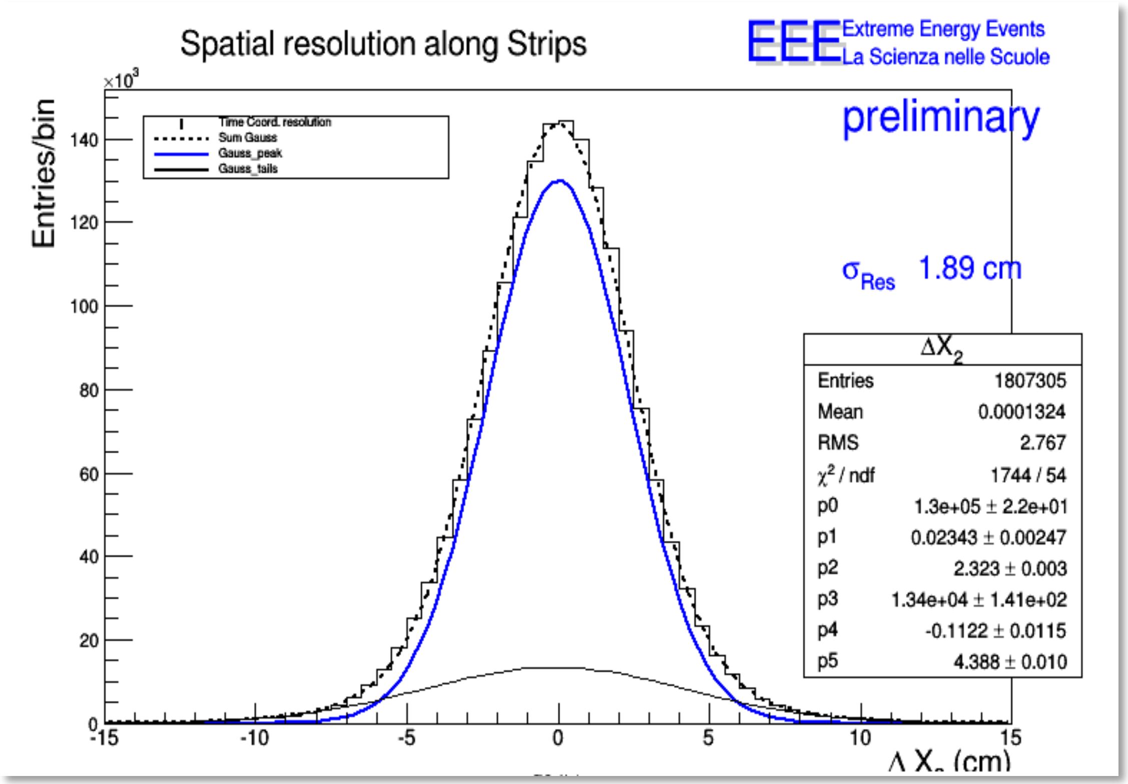
✓ distribution used to measure $\sigma_t = \sqrt{3/2}\sigma_{\Delta T}$

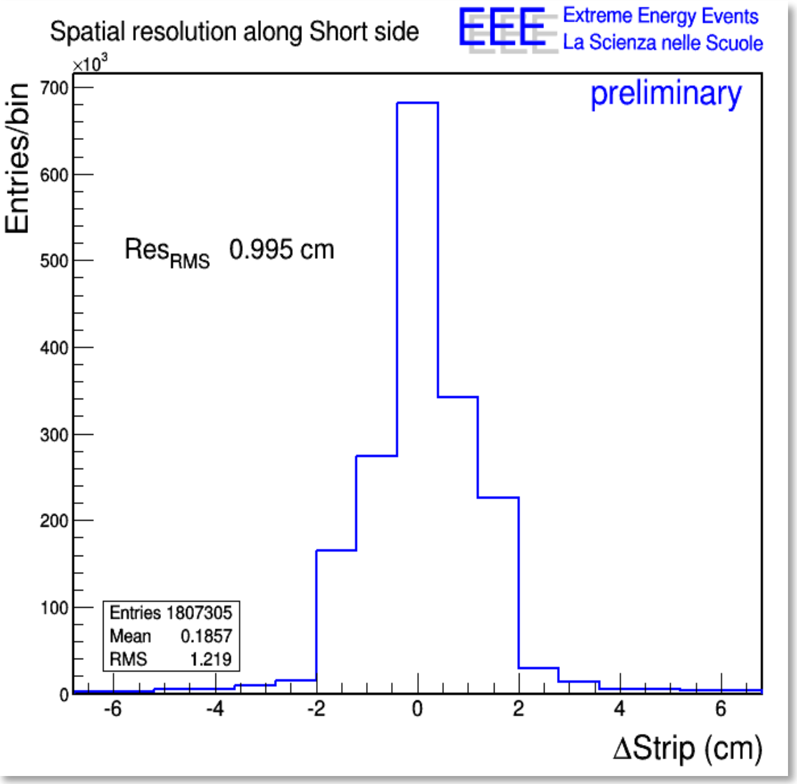
✓ $\Delta X(Y) = (X(Y)_{bot} + X(Y)_{top})/2 - X(Y)_{mid}$

expected x(y) coordinate
on the middle chamber

x(y) coordinate measured
on the middle chamber

Spatial resolution





- ✓ new analyser $\sigma_Y = \sqrt{3}/2\sigma_{\Delta Y}$ ~ 1.2 cm
- ✓ $\sigma_x = \sqrt{3}/2\sigma_{\Delta Y}$ ~ 1 cm

- ✓ *σ_x and σ_x already in the paper (including comparison with beam tests in 2006)*
- ✓ results from almost all telescopes available in Run 2 and Run 3
- ✓ plot showing the spatial resolutions for all available telescopes will be included in the paper

Trending plots

✓ data from Run 2 and Run 3

✓ stability garanteed for a few telescopes in the same period

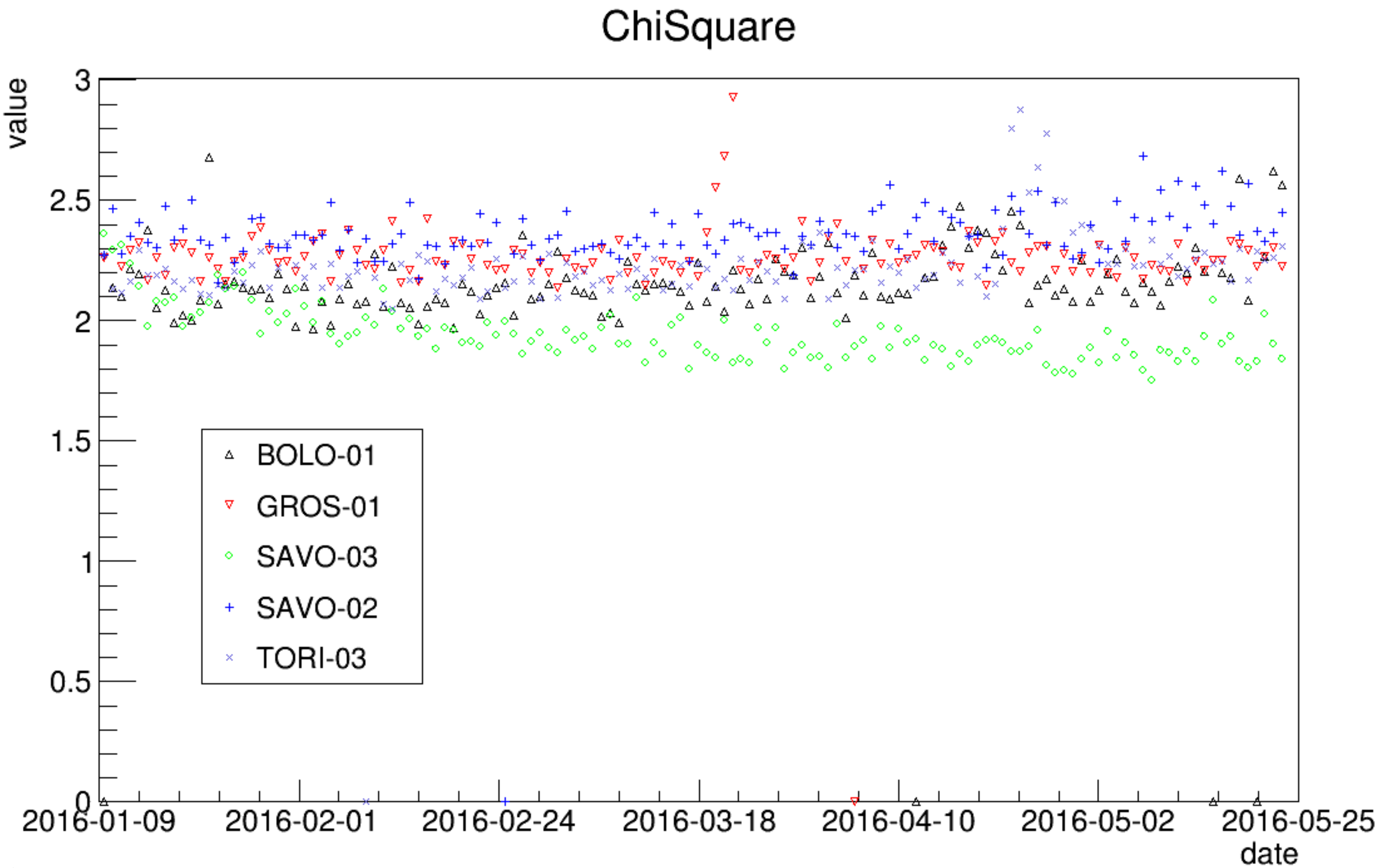
✓ some good results expecially on TOF, χ^2 and multiplicity

✓ some results a bit more problematic (included in the paper at the moment with a “positive view”)

✓ **need to decide** whether to show HV and rate trends or not

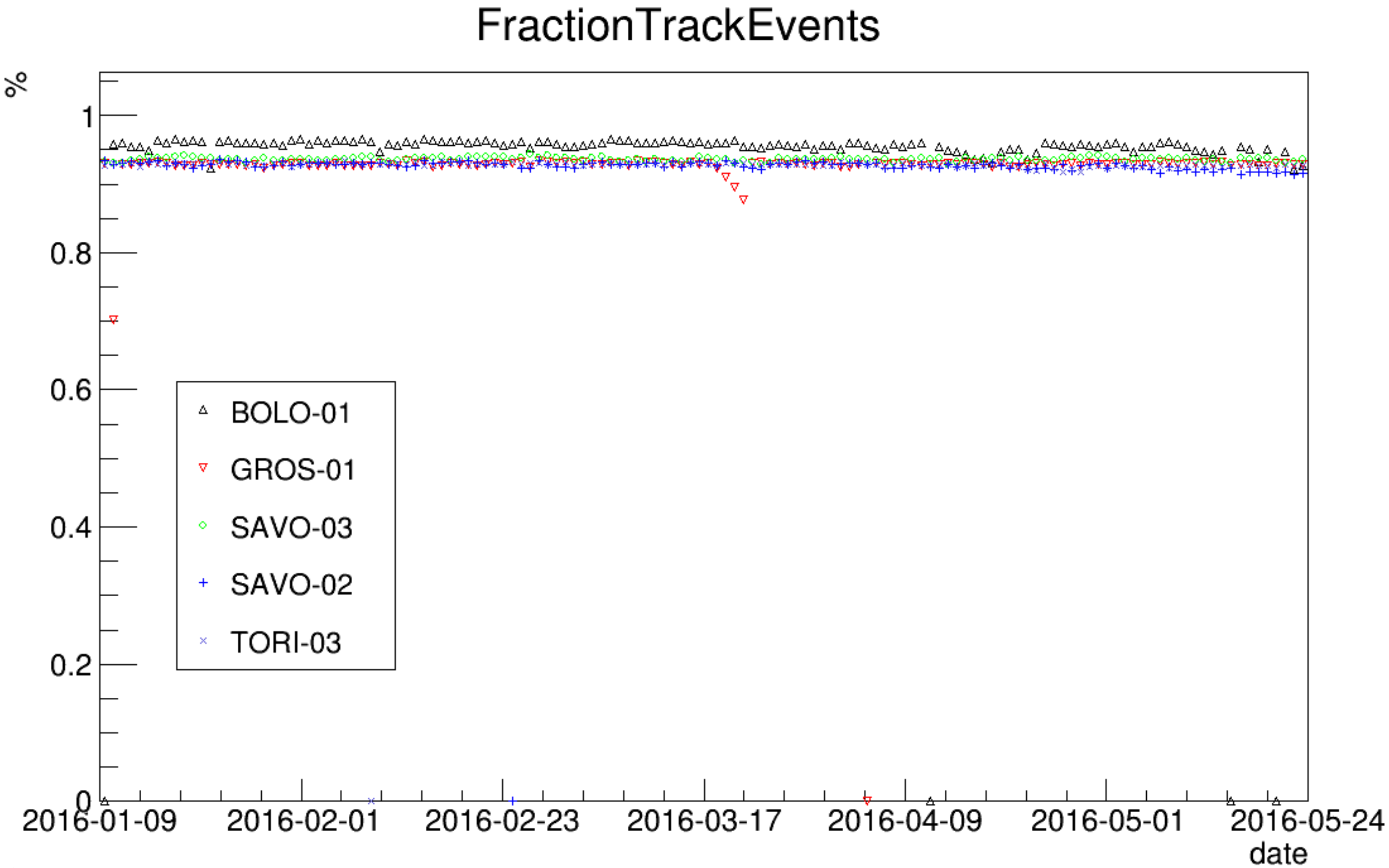
✓ *section to be written in the paper*

Trending plots



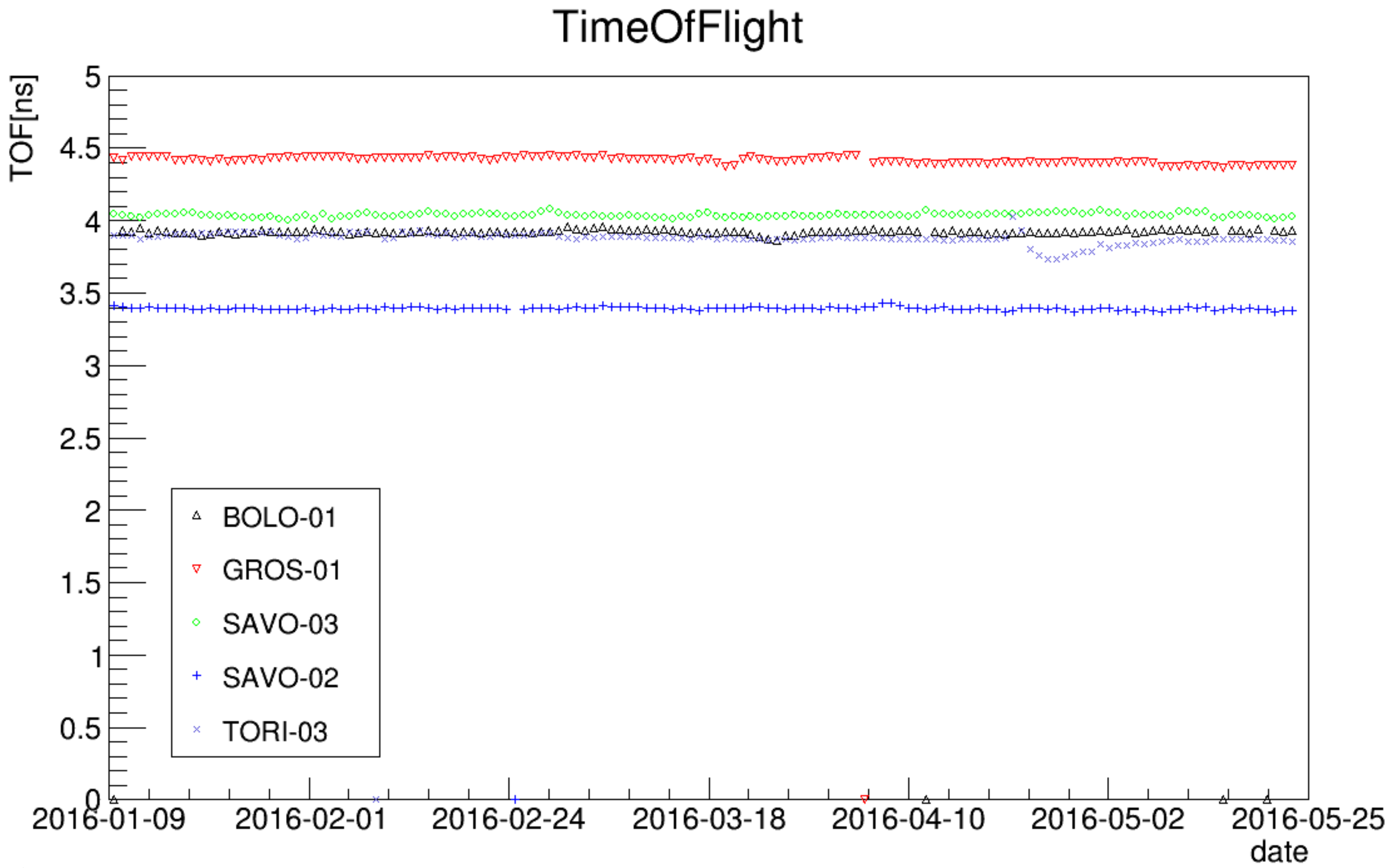
- ✓ mean value for 5 telescopes is stable over 5 months
- ✓ small increase for one of them on a couple of days

Trending plots



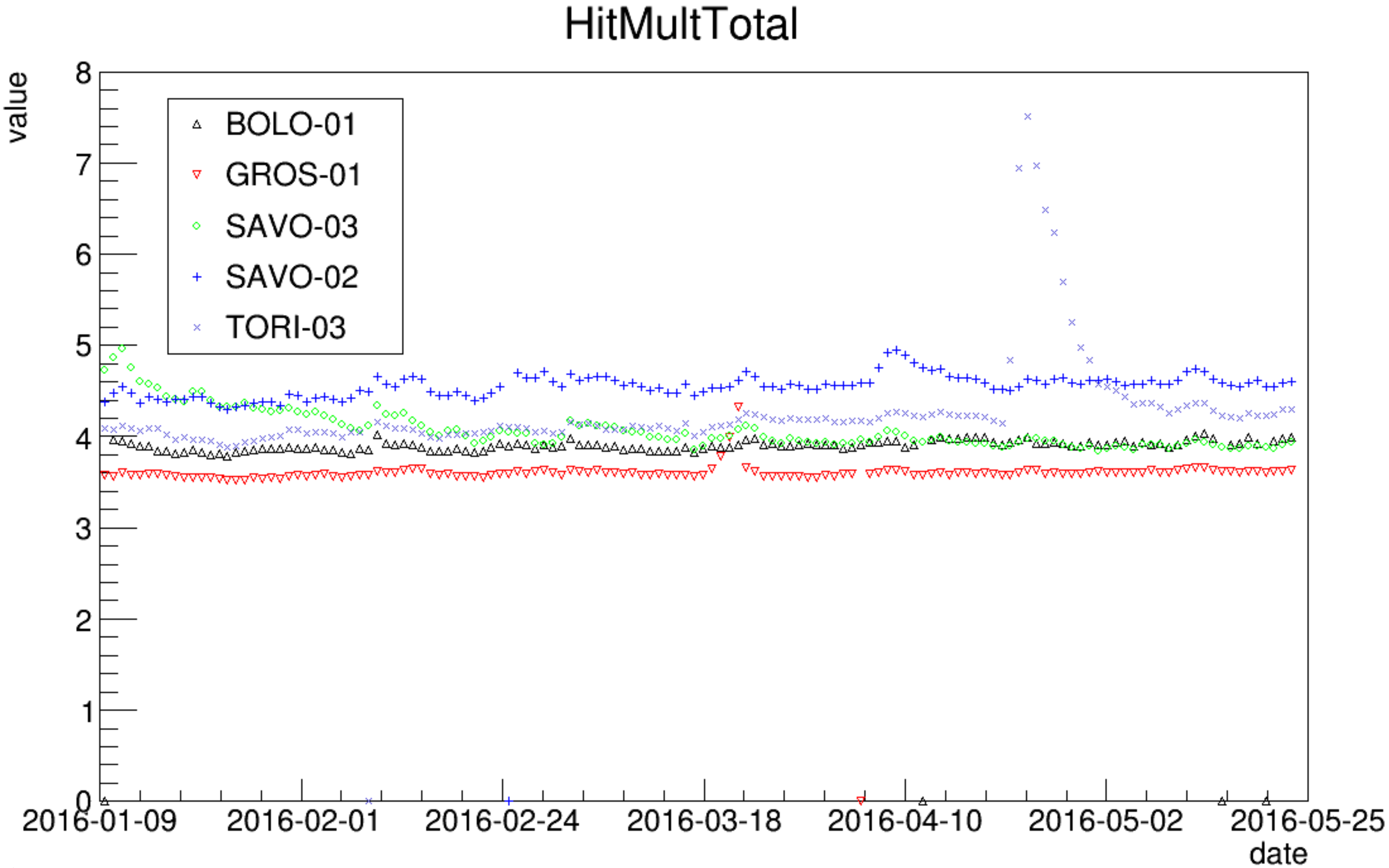
- ✓ fraction of good tracks 5 telescopes is stable over 5 months
- ✓ small drop for one of them on a couple of days

Trending plots



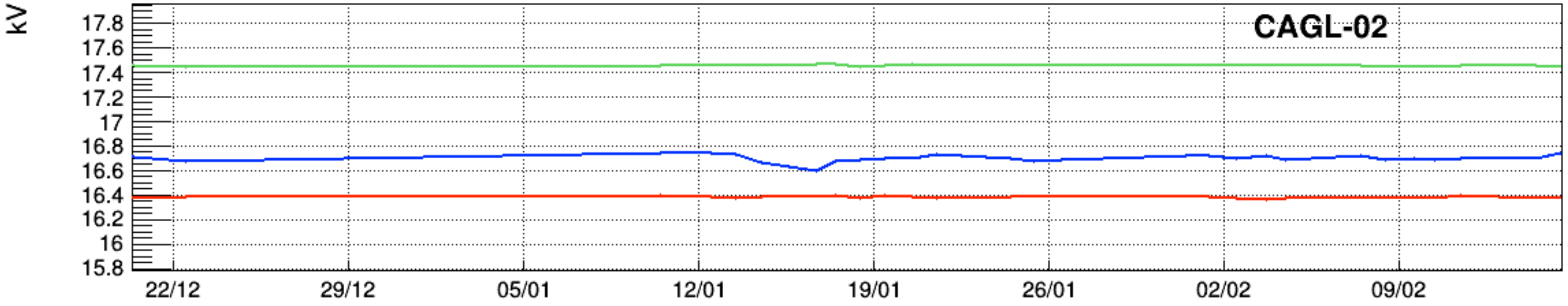
- ✓ mean value for 5 telescopes is stable over 5 months
- ✓ small drop for one of them on a few days

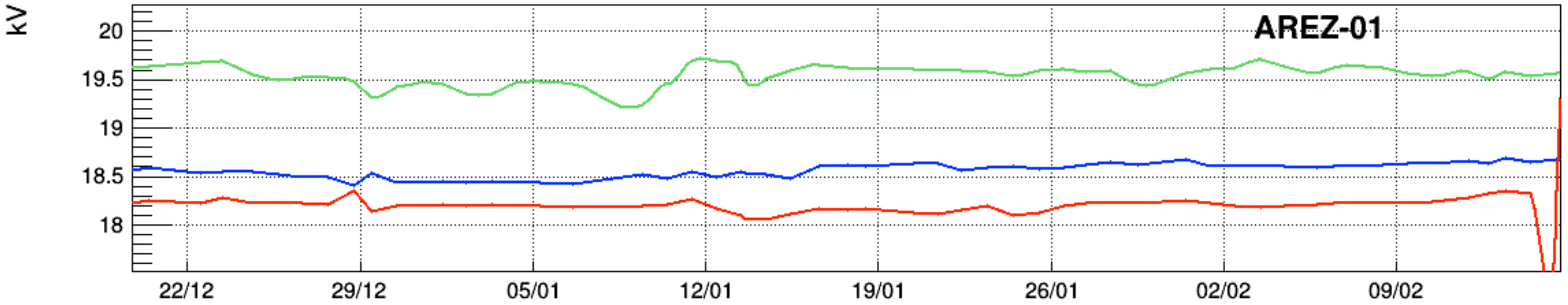
Trending plots

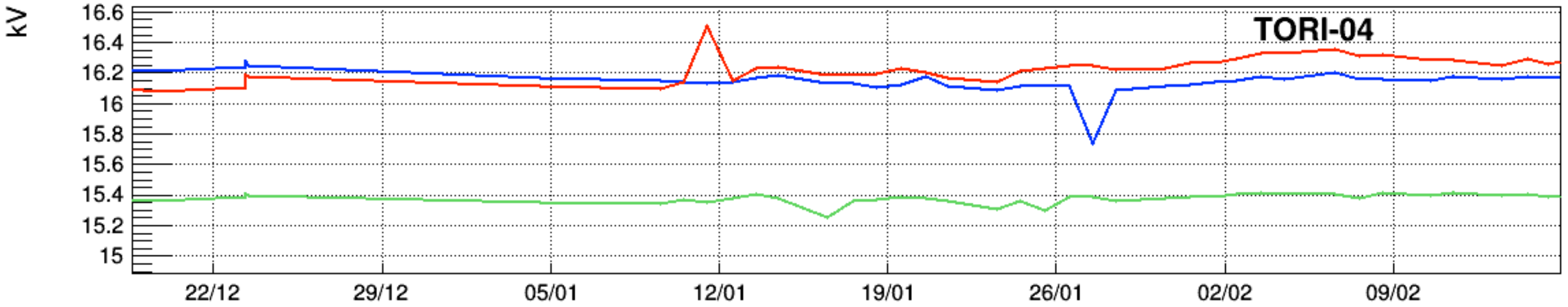


- ✓ multiplicity for 5 telescopes is stable over 5 months
- ✓ important increase for one of them on a few days (due to some sudden noise)

Trending plots

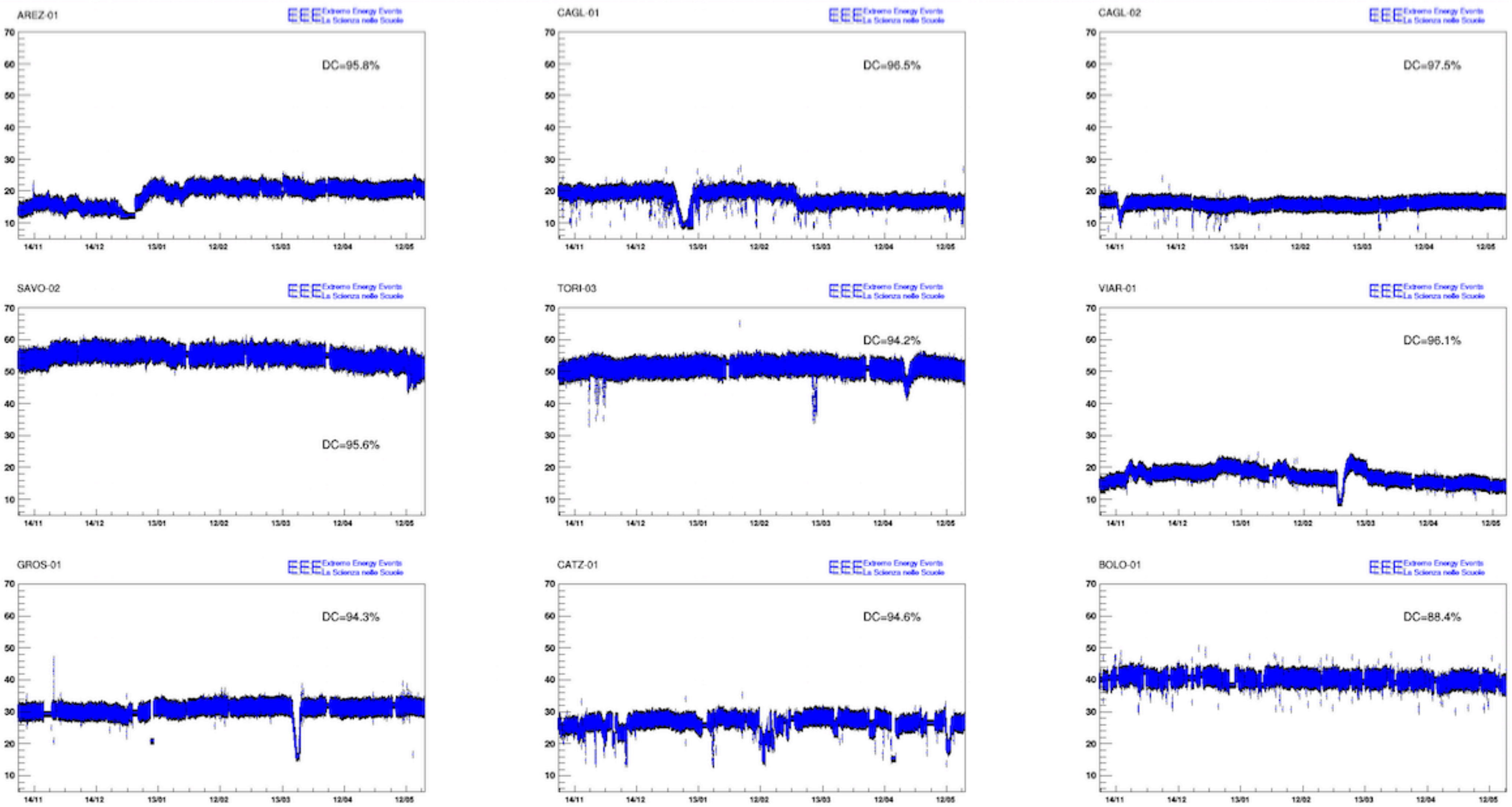






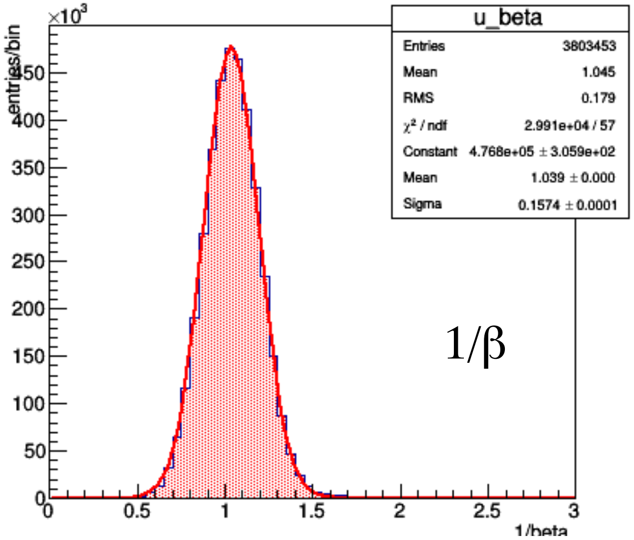
- ✓ HV stability declared by the manifacturer is 1 kV at full load (10 kV)
- ✓ stability on less than 2 months for 3 telescopes only
- ✓ possibility to improve the stability by controlling T in the room or by applying online corrections
- ✓ do we want to show this trend?

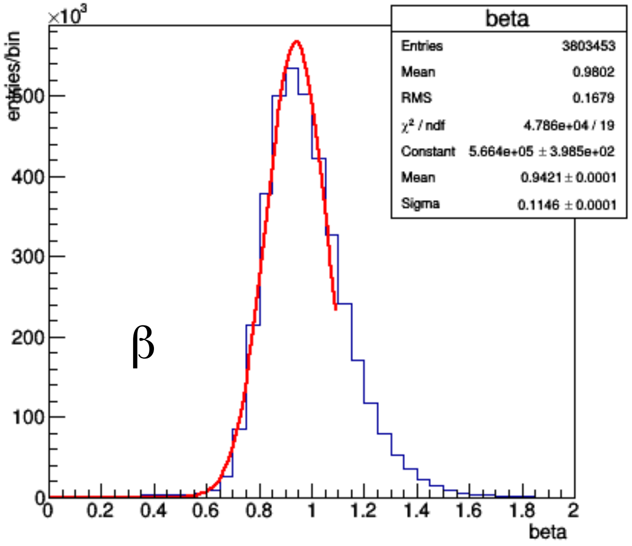
Trending plots



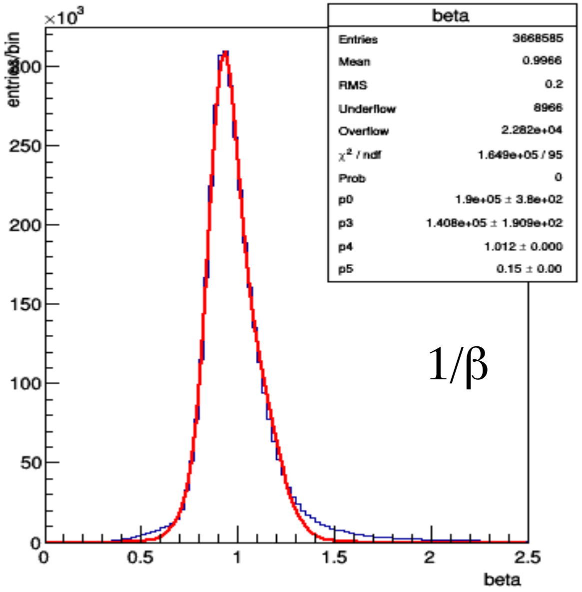
- ✓ stability on 4 months for 9 telescopes in Run 2 (to be checked in Run 3)
- ✓ many drops present in these cases
- ✓ do we want to show this trend?

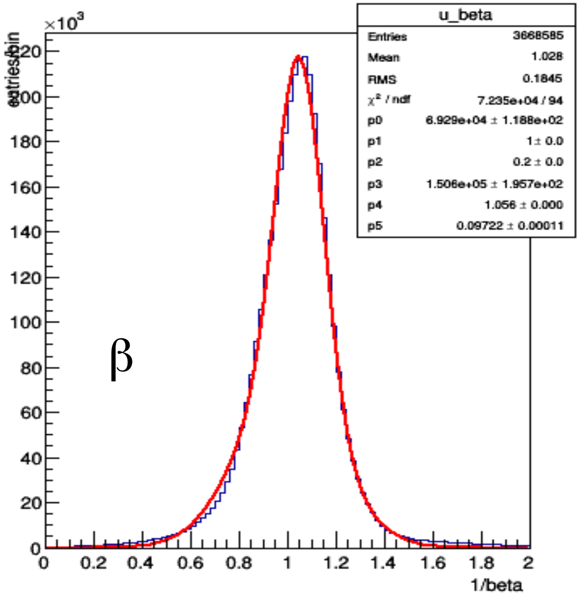
β and $1/\beta$ distributions





SAVO-02

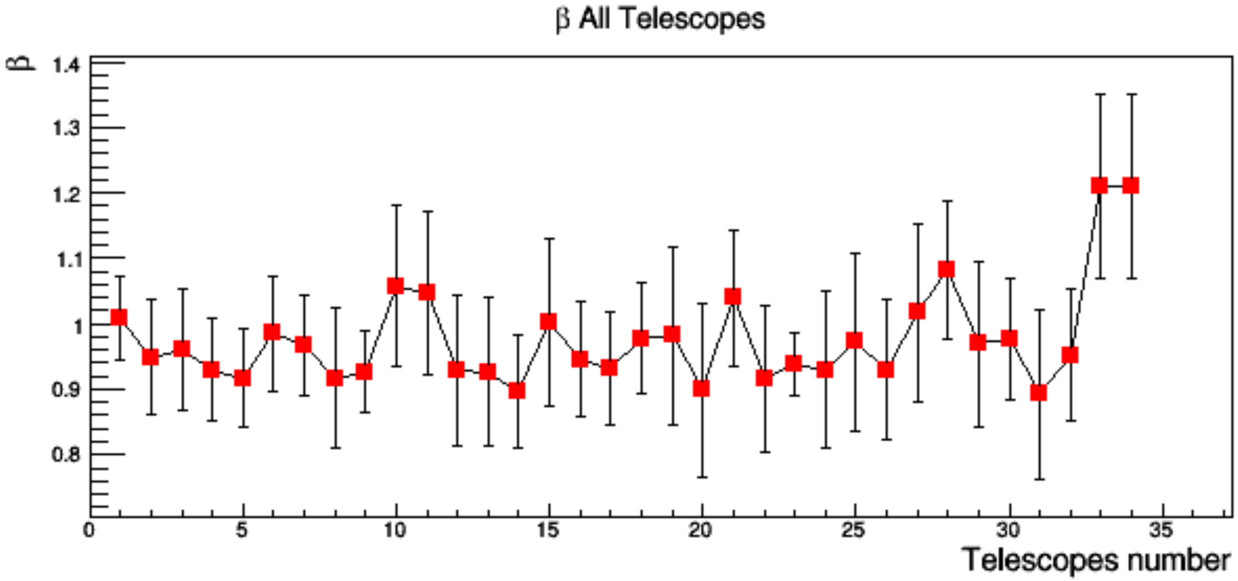


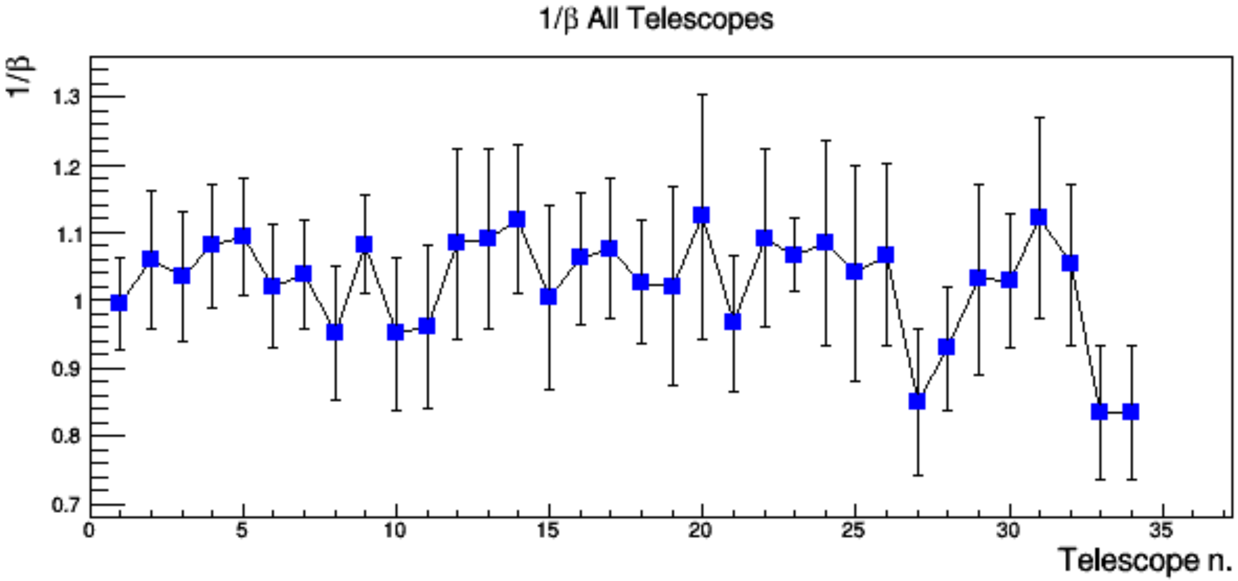


TORI-03

- ✓ results from almost all telescopes available in Run 2 and Run 3
- ✓ plot showing the β and $1/\beta$ for all available telescopes will be included in the paper

β and 1/β distributions

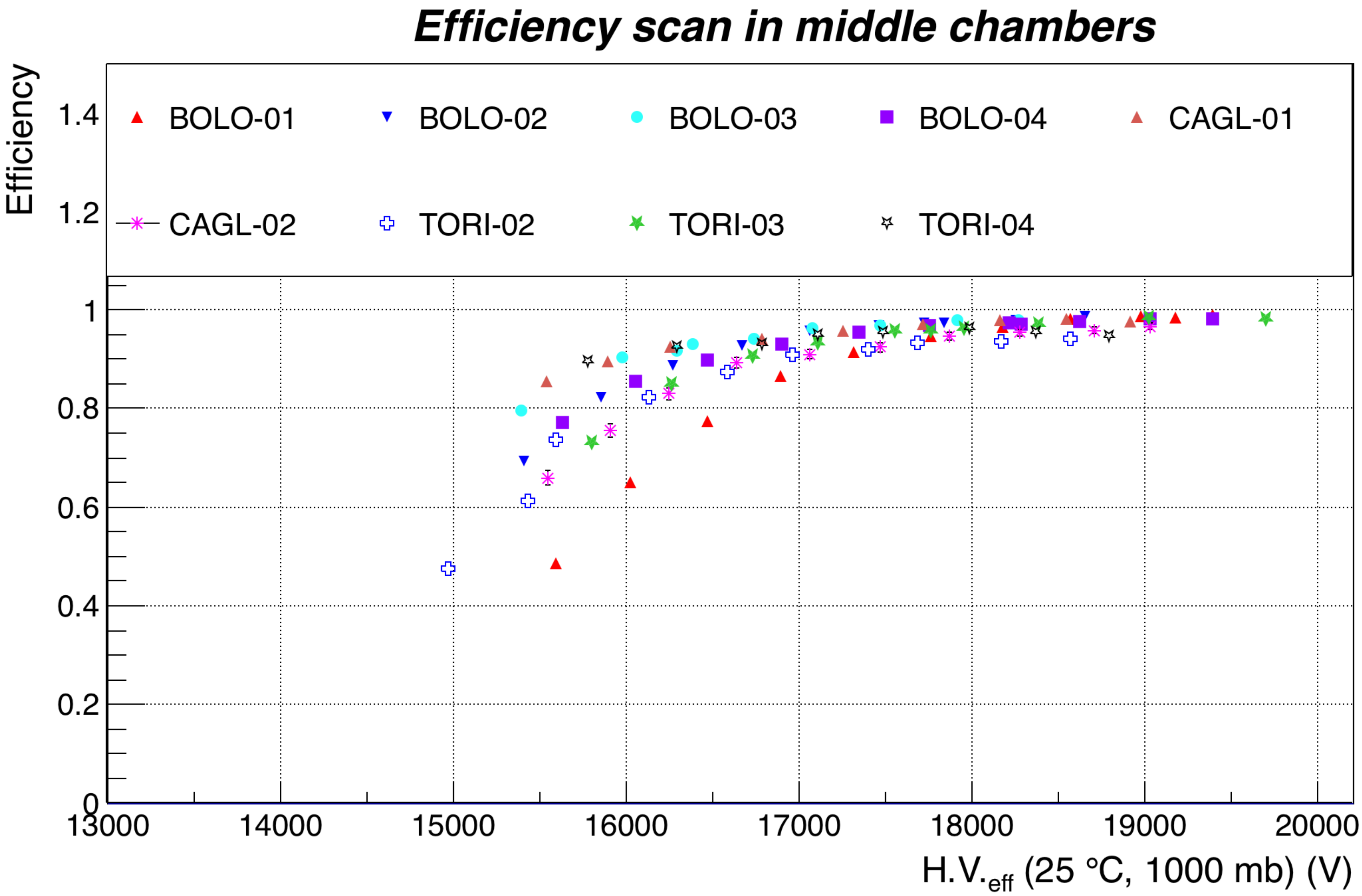




labels with the names of the telescopes will be be in these plots, rather than the numbers..

- ✓ *section to be written in the paper*
- ✓ results from almost all telescopes available in Run 2 and Run 3
- ✓ plot showing the β and 1/β for all available telescopes will be included in the paper

Efficiency (internal trigger)



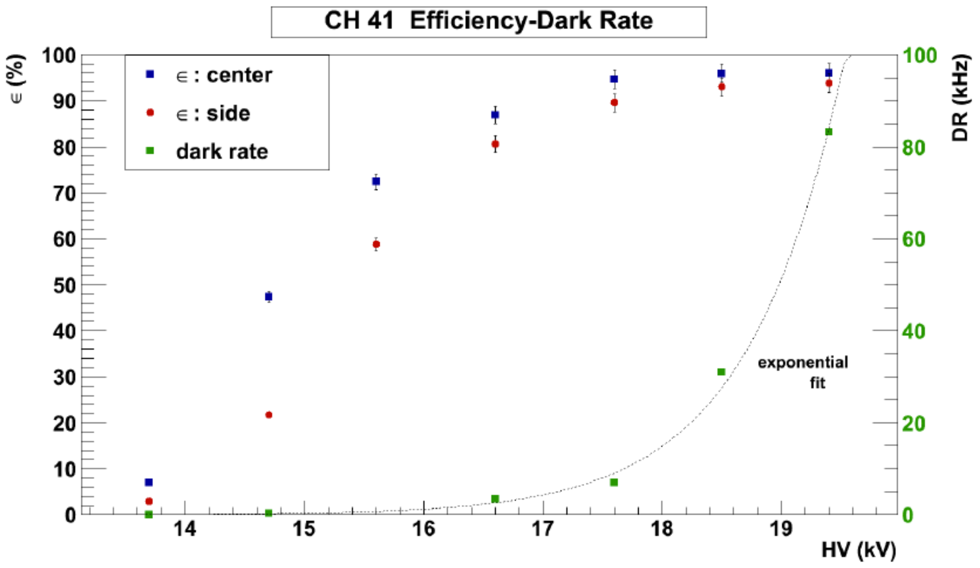
- ✓ plateau starts around 17 kV for all telescopes
- ✓ HV corrected by T and p
- ✓ *already in the paper (including comparison with beam tests in 2006)*

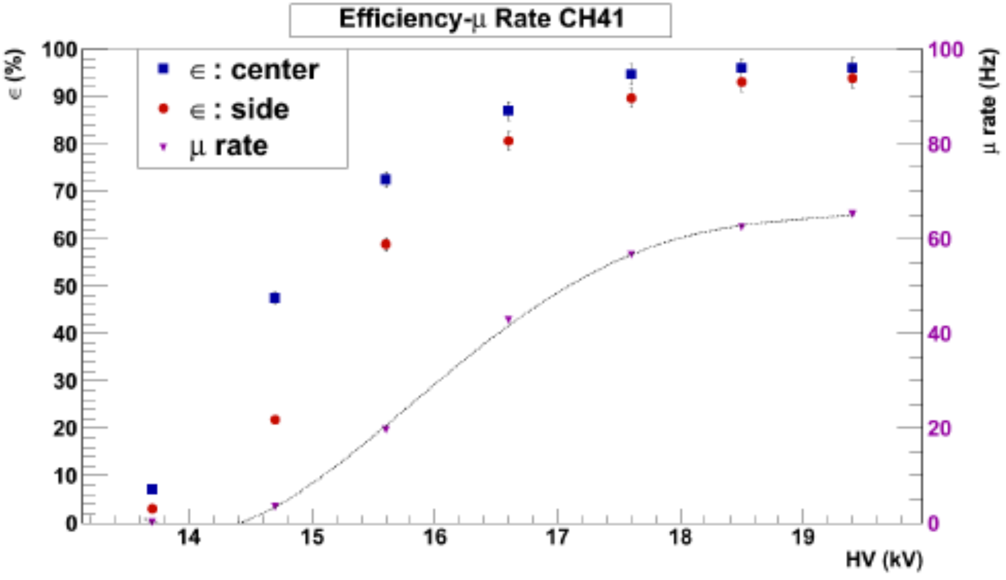
Efficiency (external trigger)

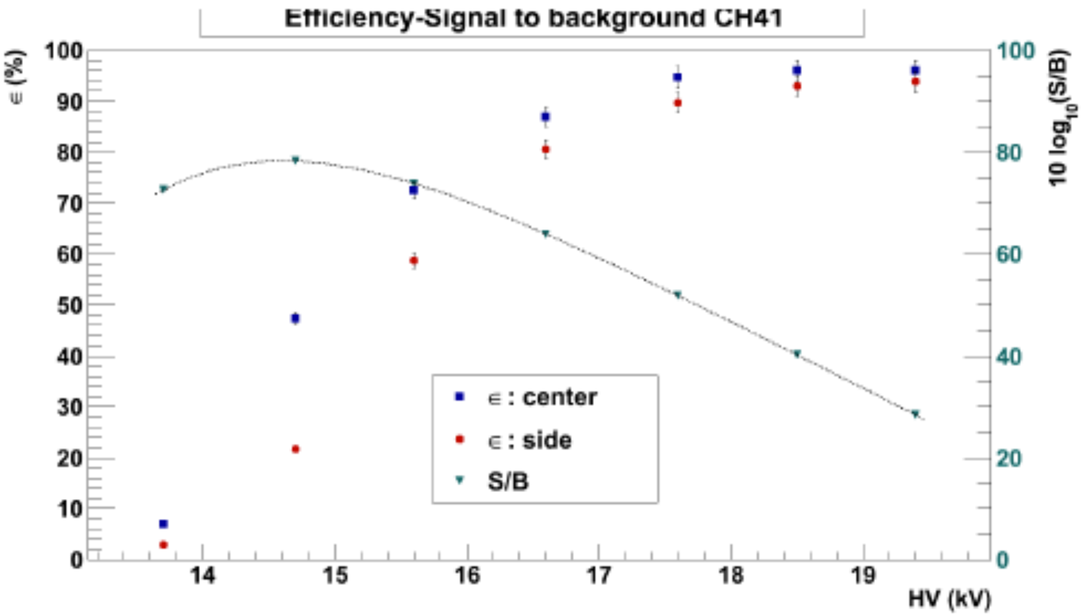
- ✓ measurement performed on TORI-03 with 2x2x25 cm^3 scintillators as trigger system
- ✓ HV scan
- ✓ S/B estimation
- ✓ muon rate corrected by eff ($\mu = R\varepsilon$)

section to be written in the paper

Efficiency (external trigger)



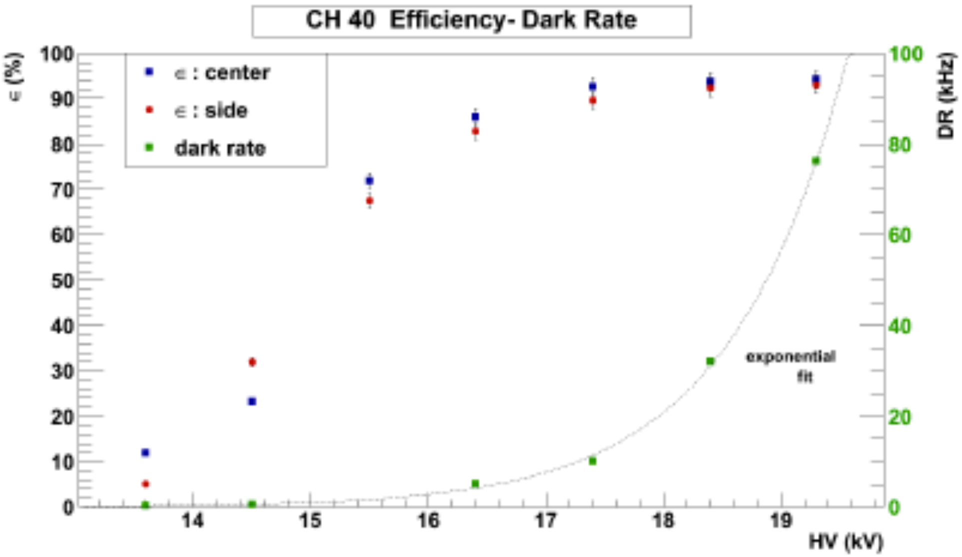


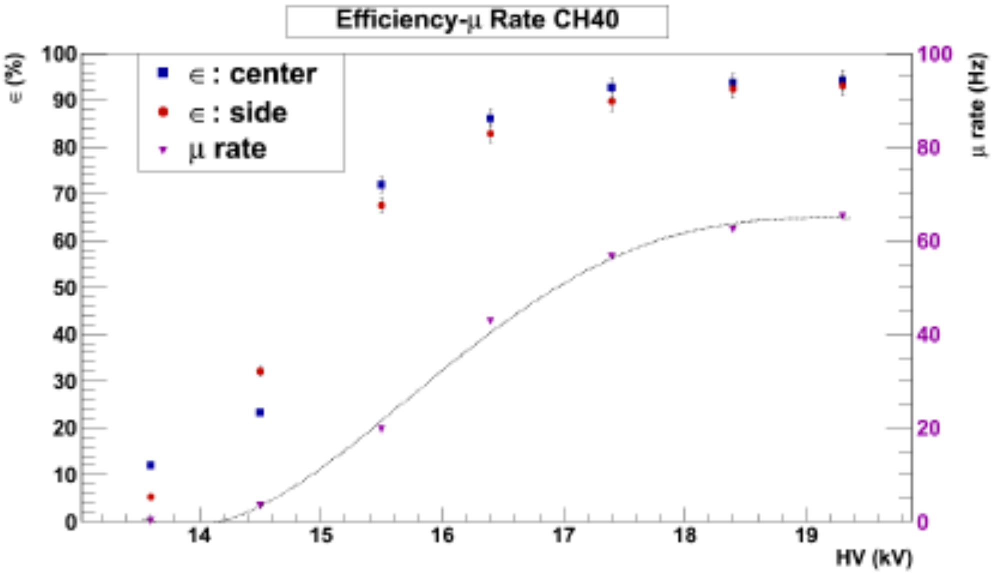


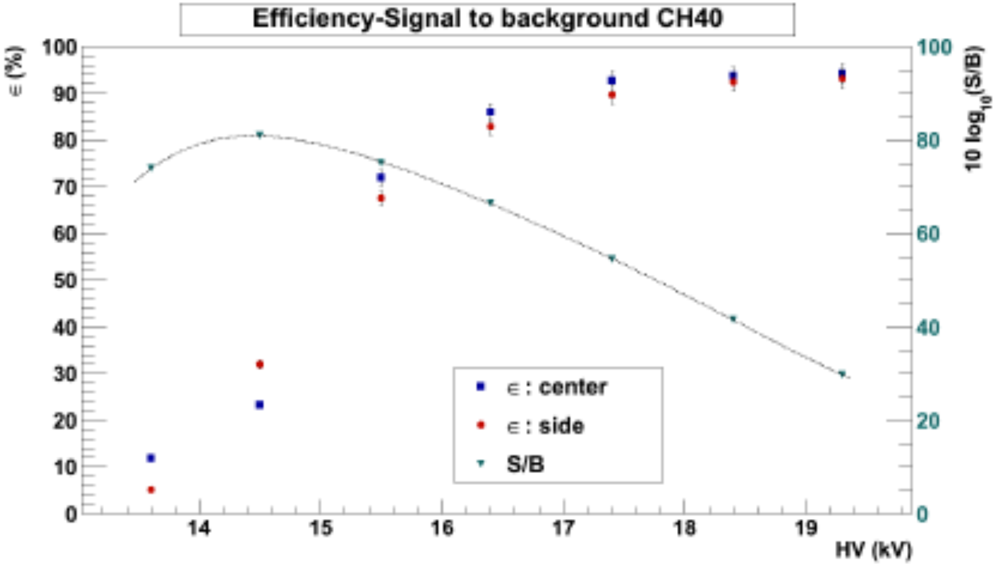
Background= Drch40*DRch41*DRch42*(Δt)^2
Δt= 35,5 ns

section to be written in the paper

Efficiency (external trigger)



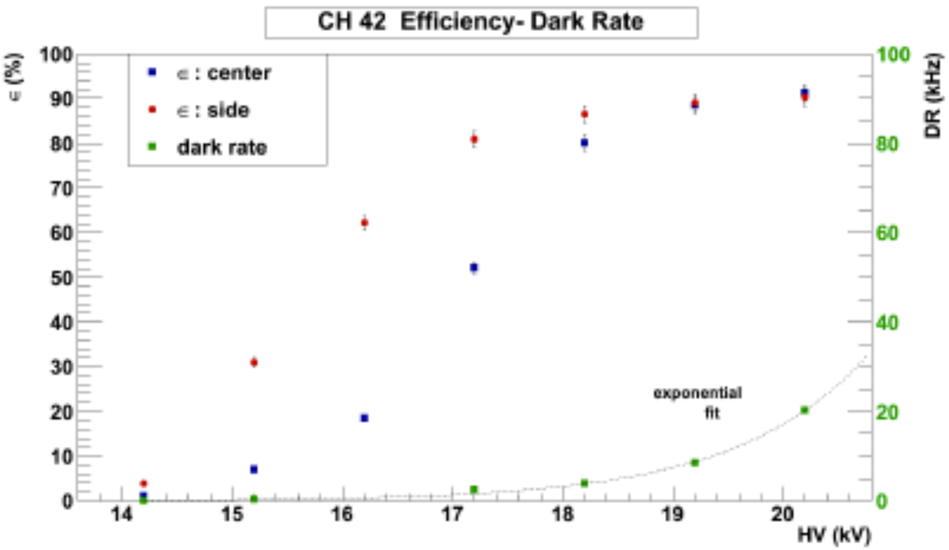


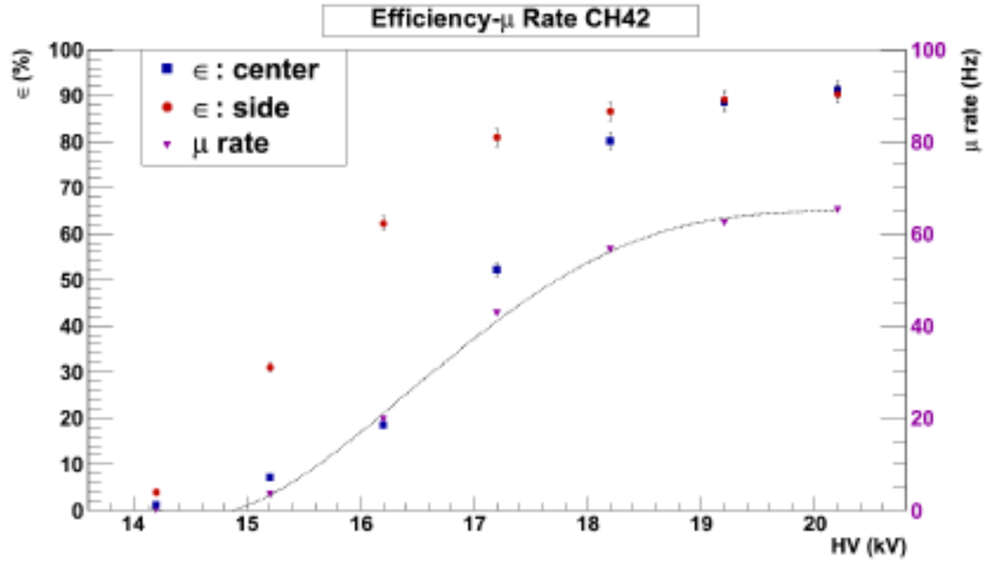


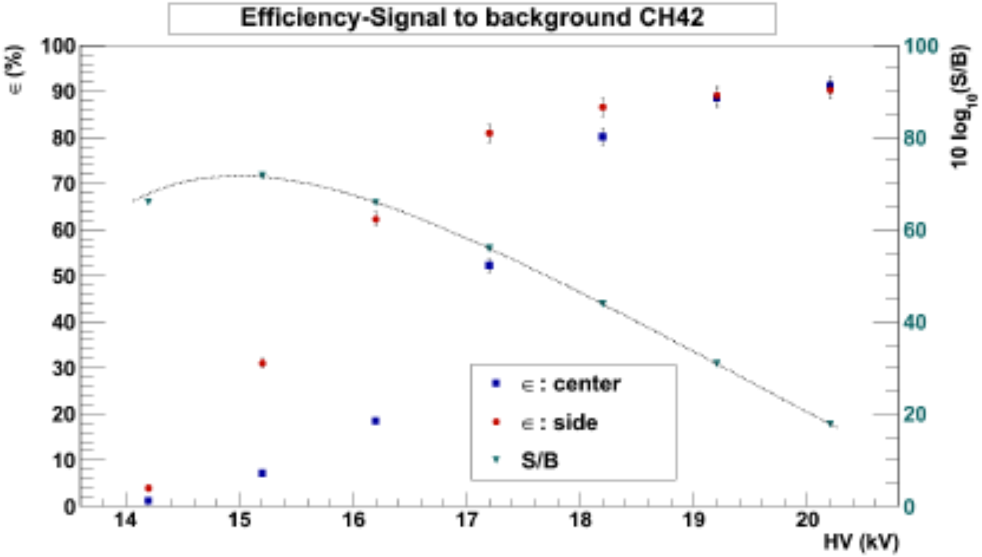
Background= Drch40*DRch41*DRch42*$(\Delta t)^2$
Δt= 35,5 ns

section to be written in the paper

Efficiency (external trigger)


CH 42 Efficiency- Dark Rate

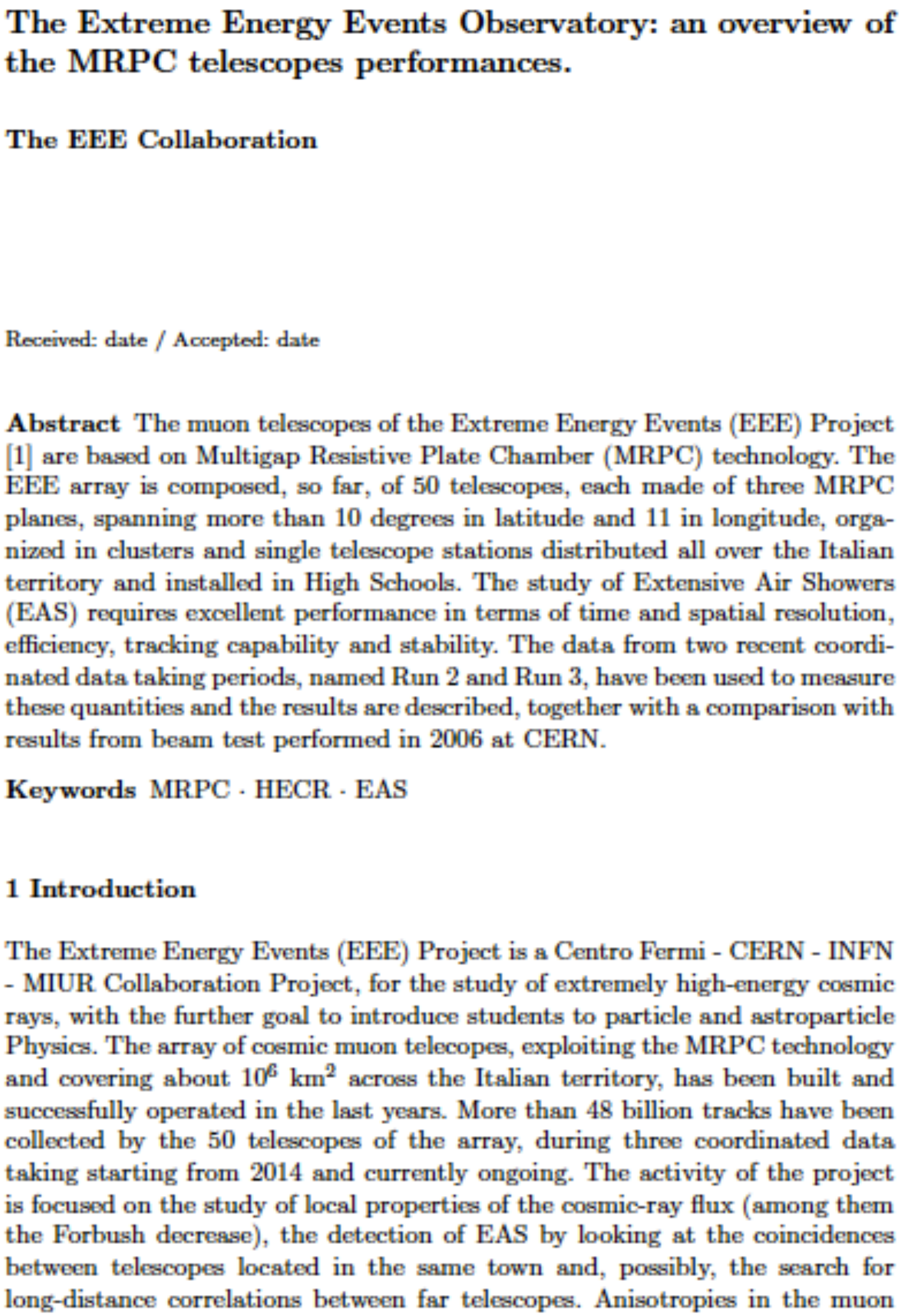

Efficiency-μ Rate CH42


Efficiency-Signal to background CH42

Background= Drch40*DRch41*DRch42*$(\Delta t)^2$
Δt= 35,5 ns

section to be written in the paper

Paper



The Extreme Energy Events Observatory: an overview of the MRPC telescopes performances.

The EEE Collaboration

Received: date / Accepted: date

Abstract The muon telescopes of the Extreme Energy Events (EEE) Project [1] are based on Multigap Resistive Plate Chamber (MRPC) technology. The EEE array is composed, so far, of 50 telescopes, each made of three MRPC planes, spanning more than 10 degrees in latitude and 11 in longitude, organized in clusters and single telescope stations distributed all over the Italian territory and installed in High Schools. The study of Extensive Air Showers (EAS) requires excellent performance in terms of time and spatial resolution, efficiency, tracking capability and stability. The data from two recent coordinated data taking periods, named Run 2 and Run 3, have been used to measure these quantities and the results are described, together with a comparison with results from beam test performed in 2006 at CERN.

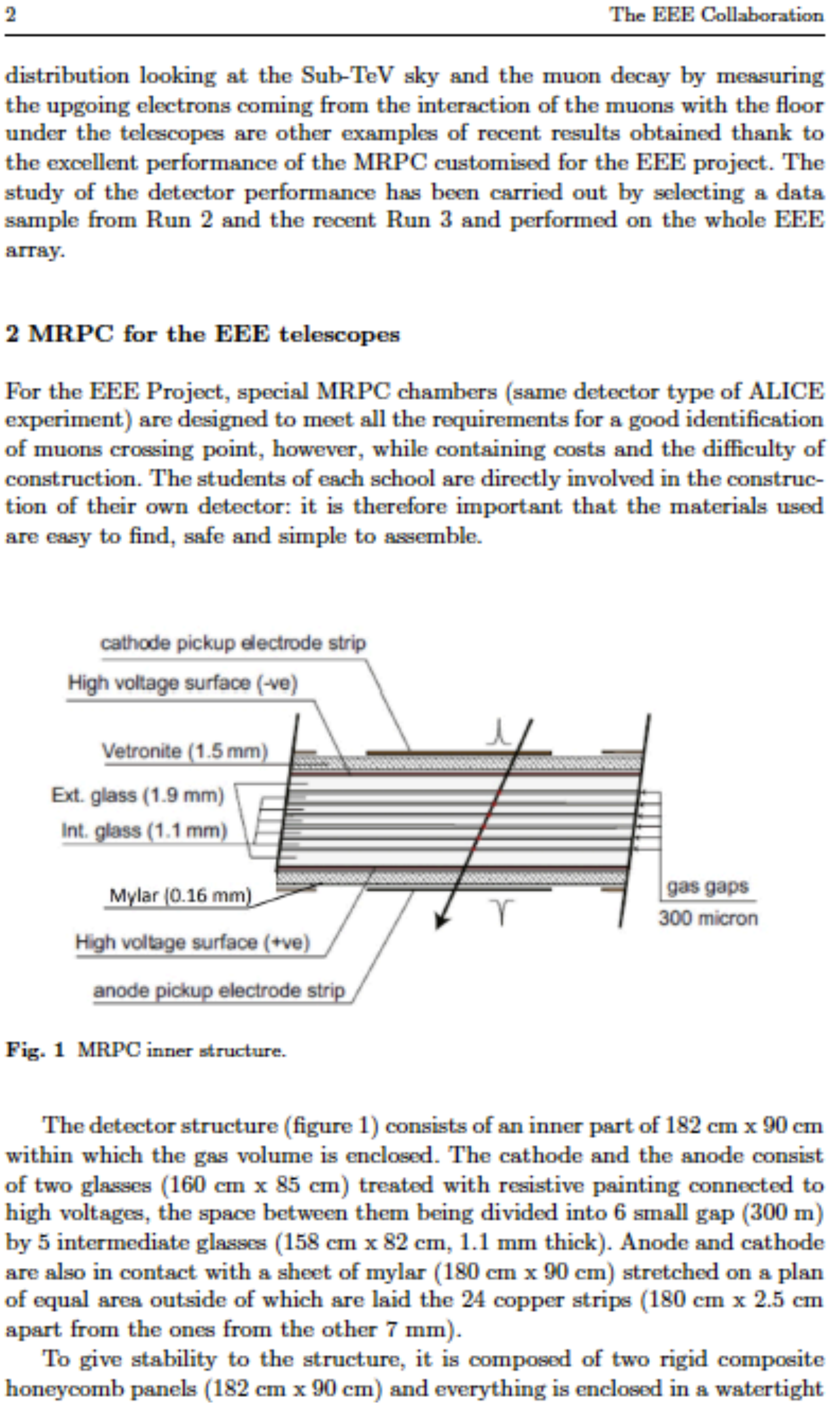
Keywords MRPC · HECR · EAS

1 Introduction

The Extreme Energy Events (EEE) Project is a Centro Fermi - CERN - INFN - MIUR Collaboration Project, for the study of extremely high-energy cosmic rays, with the further goal to introduce students to particle and astroparticle Physics. The array of cosmic muon telecopes, exploiting the MRPC technology and covering about 10^6 km^2 across the Italian territory, has been built and successfully operated in the last years. More than 48 billion tracks have been collected by the 50 telescopes of the array, during three coordinated data taking starting from 2014 and currently ongoing. The activity of the project is focused on the study of local properties of the cosmic-ray flux (among them the Forbush decrease), the detection of EAS by looking at the coincidences between telescopes located in the same town and, possibly, the search for long-distance correlations between far telescopes. Anisotropies in the muon

- ✓ abstract and introduction written
- ✓ some references to the needs for the analysis performed by the EEE Collaboration are present

Paper



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distribution looking at the Sub-TeV sky and the muon decay by measuring the upgoing electrons coming from the interaction of the muons with the floor under the telescopes are other examples of recent results obtained thank to the excellent performance of the MRPC customised for the EEE project. The study of the detector performance has been carried out by selecting a data sample from Run 2 and the recent Run 3 and performed on the whole EEE array.

2 MRPC for the EEE telescopes

For the EEE Project, special MRPC chambers (same detector type of ALICE experiment) are designed to meet all the requirements for a good identification of muons crossing point, however, while containing costs and the difficulty of construction. The students of each school are directly involved in the construction of their own detector: it is therefore important that the materials used are easy to find, safe and simple to assemble.

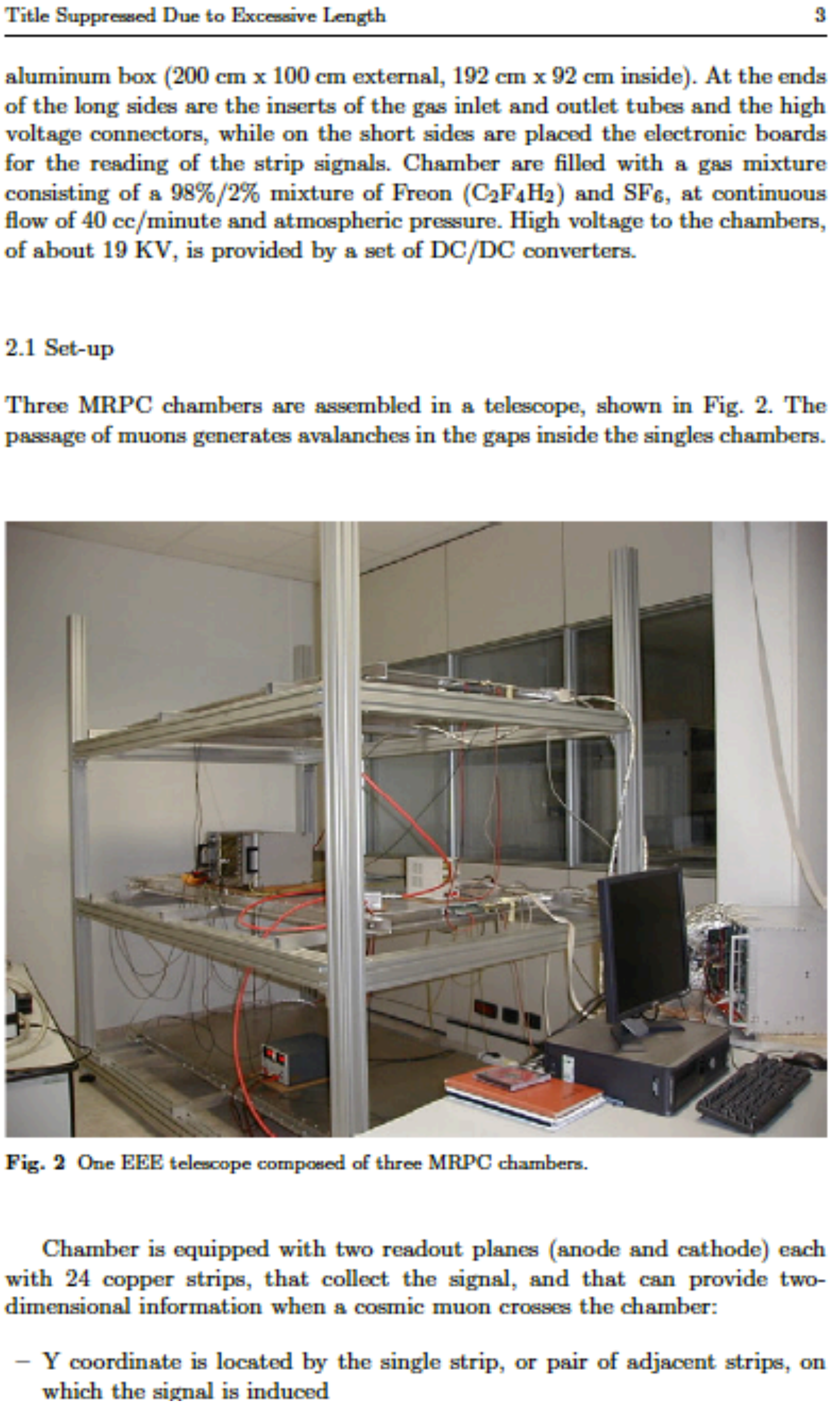
Fig. 1 MRPC inner structure.

The detector structure (figure 1) consists of an inner part of 182 cm x 90 cm within which the gas volume is enclosed. The cathode and the anode consist of two glasses (160 cm x 85 cm) treated with resistive painting connected to high voltages, the space between them being divided into 6 small gap (300 m) by 5 intermediate glasses (158 cm x 82 cm, 1.1 mm thick). Anode and cathode are also in contact with a sheet of mylar (180 cm x 90 cm) stretched on a plan of equal area outside of which are laid the 24 copper strips (180 cm x 2.5 cm apart from the ones from the other 7 mm).

To give stability to the structure, it is composed of two rigid composite honeycomb panels (182 cm x 90 cm) and everything is enclosed in a watertight

- ✓ detector description and experiment setup written

Paper



aluminum box (200 cm x 100 cm external, 192 cm x 92 cm inside). At the ends of the long sides are the inserts of the gas inlet and outlet tubes and the high voltage connectors, while on the short sides are placed the electronic boards for the reading of the strip signals. Chamber are filled with a gas mixture consisting of a 98%/2% mixture of Freon ($C_2F_4H_2$) and SF_6, at continuous flow of 40 cc/minute and atmospheric pressure. High voltage to the chambers, of about 19 KV, is provided by a set of DC/DC converters.

2.1 Set-up

Three MRPC chambers are assembled in a telescope, shown in Fig. 2. The passage of muons generates avalanches in the gaps inside the singles chambers.

Fig. 2 One EEE telescope composed of three MRPC chambers.

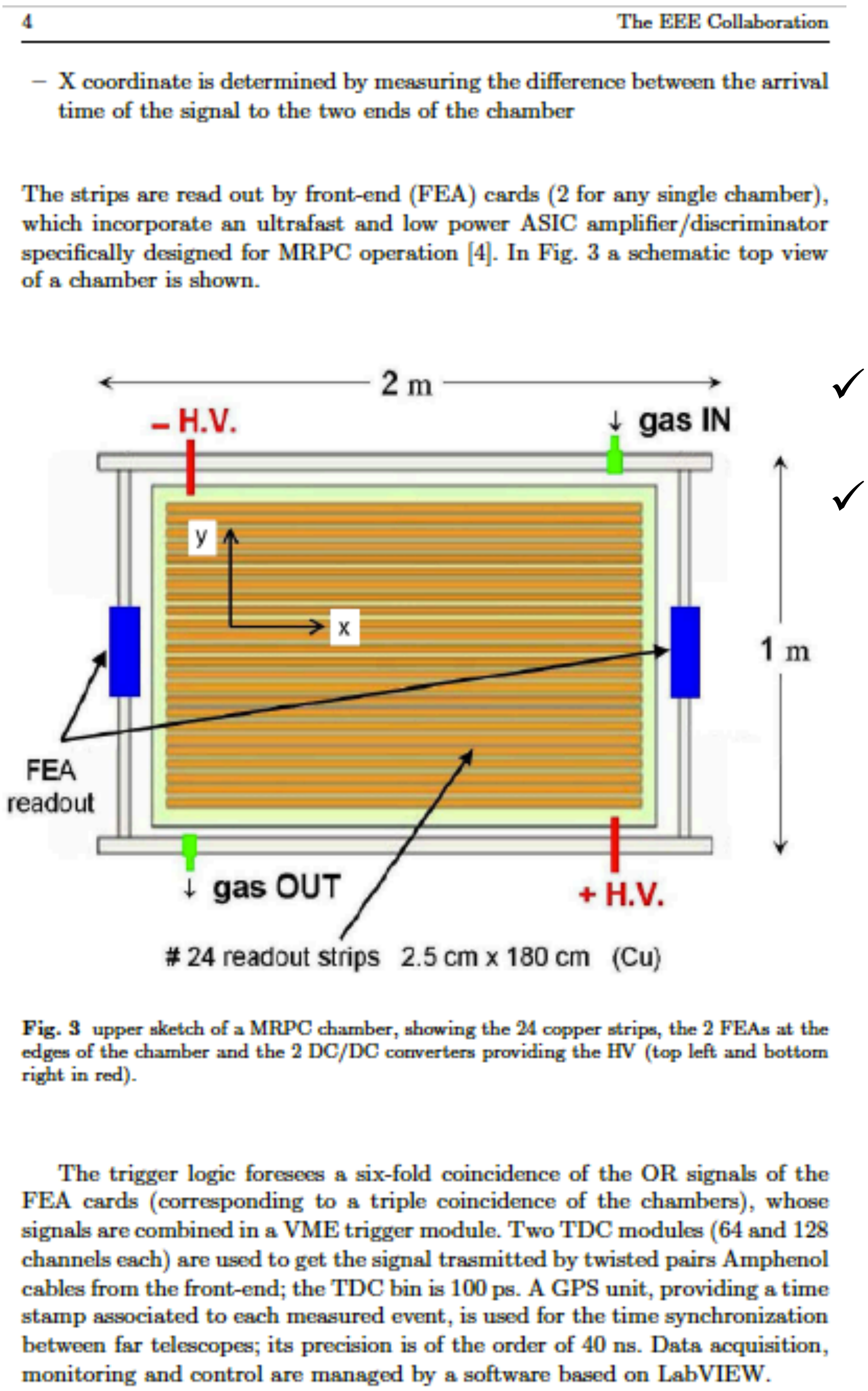
Chamber is equipped with two readout planes (anode and cathode) each with 24 copper strips, that collect the signal, and that can provide two-dimensional information when a cosmic muon crosses the chamber:

- Y coordinate is located by the single strip, or pair of adjacent strips, on which the signal is induced

✓ detector description and experiment setup written

✓ picture to be replaced

Paper



– X coordinate is determined by measuring the difference between the arrival time of the signal to the two ends of the chamber

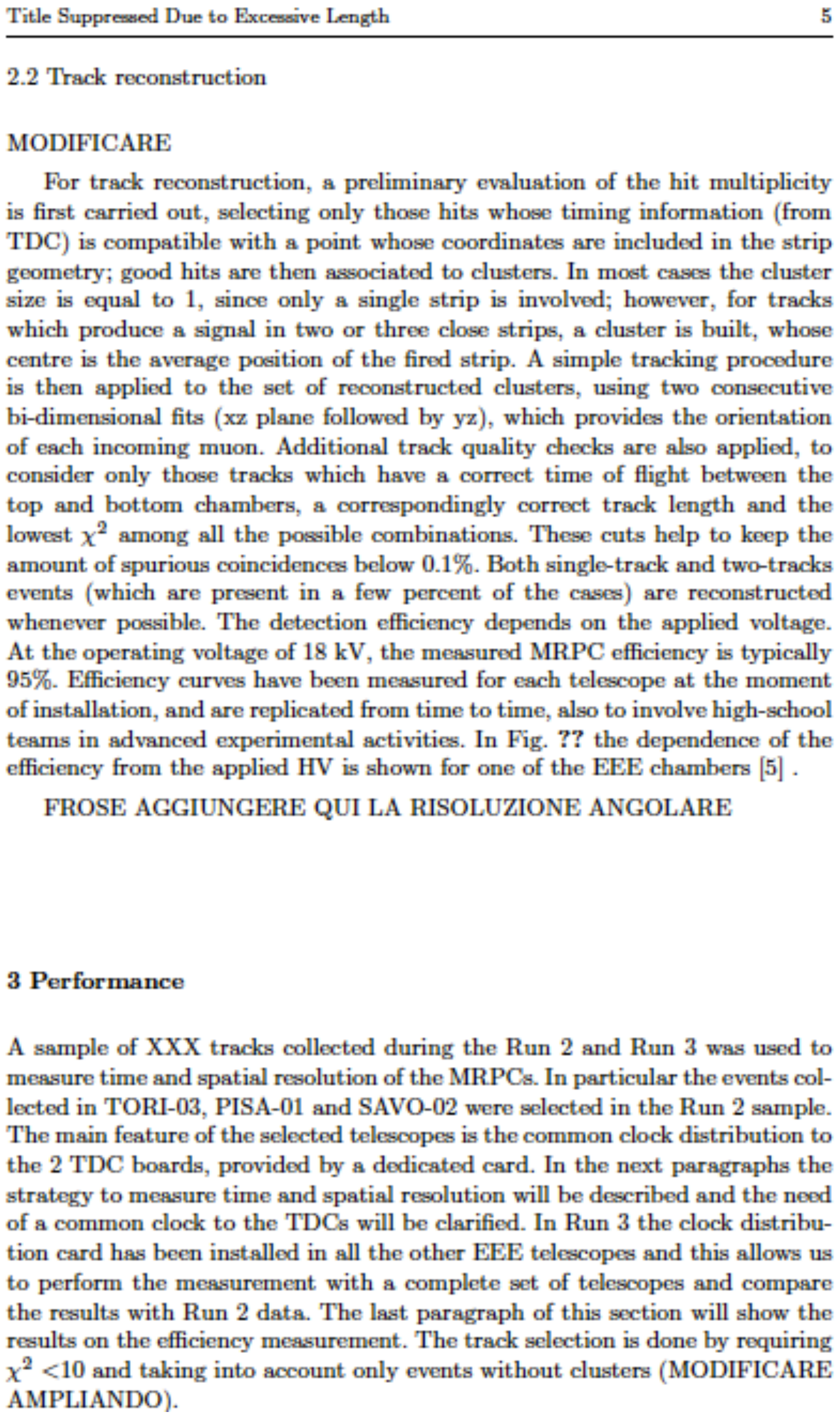
The strips are read out by front-end (FEA) cards (2 for any single chamber), which incorporate an ultrafast and low power ASIC amplifier/discriminator specifically designed for MRPC operation [4]. In Fig. 3 a schematic top view of a chamber is shown.

Fig. 3 upper sketch of a MRPC chamber, showing the 24 copper strips, the 2 FEAs at the edges of the chamber and the 2 DC/DC converters providing the HV (top left and bottom right in red).

The trigger logic foresees a six-fold coincidence of the OR signals of the FEA cards (corresponding to a triple coincidence of the chambers), whose signals are combined in a VME trigger module. Two TDC modules (64 and 128 channels each) are used to get the signal trasmitted by twisted pairs Amphenol cables from the front-end; the TDC bin is 100 ps. A GPS unit, providing a time stamp associated to each measured event, is used for the time synchronization between far telescopes; its precision is of the order of 40 ns. Data acquisition, monitoring and control are managed by a software based on LabVIEW.

- ✓ detector description and experiment setup written
- ✓ picture to be replaced? New one to be done in this case

Paper



Title Suppressed Due to Excessive Length 5

2.2 Track reconstruction

MODIFICARE

For track reconstruction, a preliminary evaluation of the hit multiplicity is first carried out, selecting only those hits whose timing information (from TDC) is compatible with a point whose coordinates are included in the strip geometry; good hits are then associated to clusters. In most cases the cluster size is equal to 1, since only a single strip is involved; however, for tracks which produce a signal in two or three close strips, a cluster is built, whose centre is the average position of the fired strip. A simple tracking procedure is then applied to the set of reconstructed clusters, using two consecutive bi-dimensional fits (xz plane followed by yz), which provides the orientation of each incoming muon. Additional track quality checks are also applied, to consider only those tracks which have a correct time of flight between the top and bottom chambers, a correspondingly correct track length and the lowest χ^2 among all the possible combinations. These cuts help to keep the amount of spurious coincidences below 0.1%. Both single-track and two-tracks events (which are present in a few percent of the cases) are reconstructed whenever possible. The detection efficiency depends on the applied voltage. At the operating voltage of 18 kV, the measured MRPC efficiency is typically 95%. Efficiency curves have been measured for each telescope at the moment of installation, and are replicated from time to time, also to involve high-school teams in advanced experimental activities. In Fig. ?? the dependence of the efficiency from the applied HV is shown for one of the EEE chambers [5] .

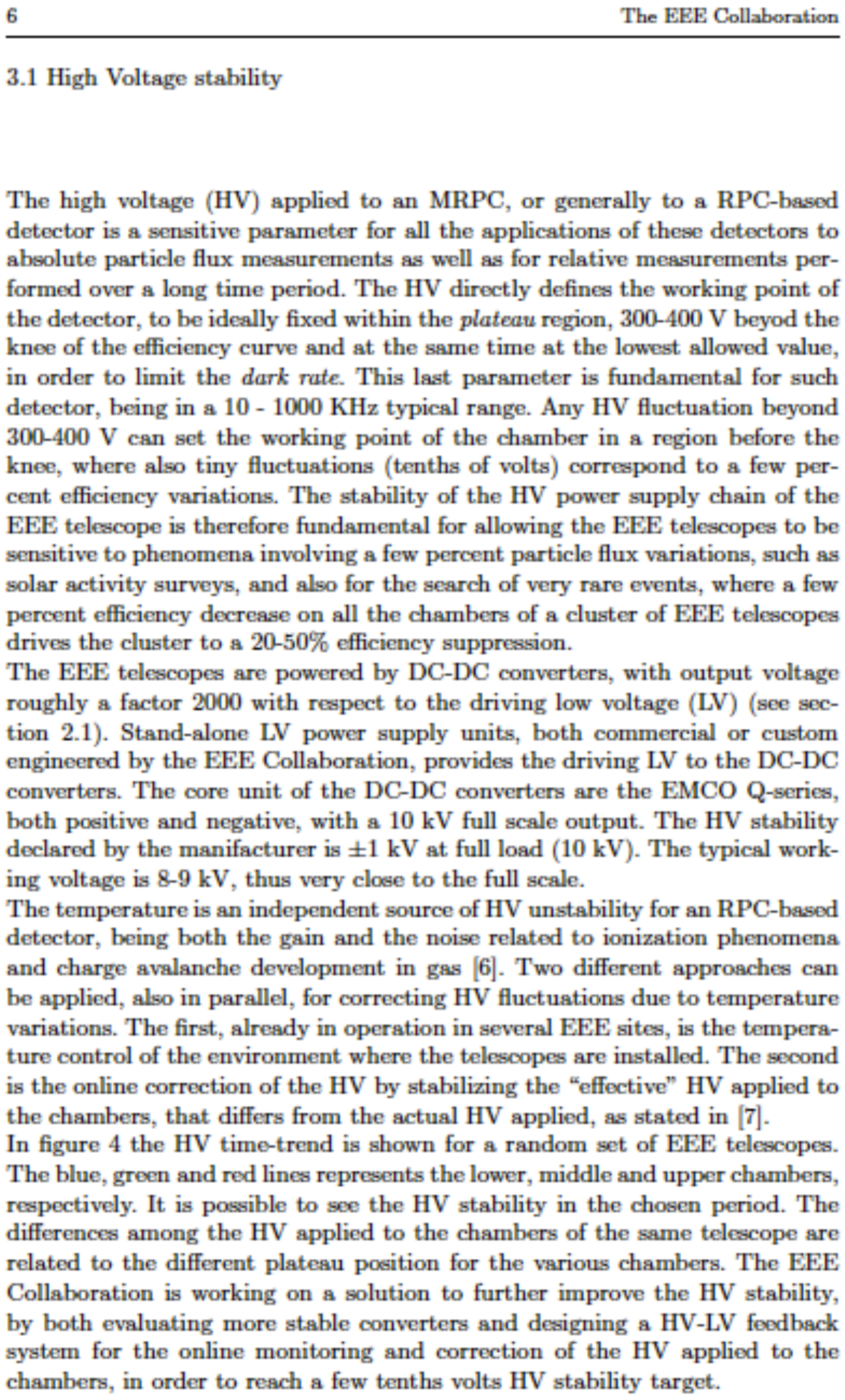
FROSE AGGIUNGERE QUI LA RISOLUZIONE ANGOLARE

3 Performance

A sample of XXX tracks collected during the Run 2 and Run 3 was used to measure time and spatial resolution of the MRPCs. In particular the events collected in TORI-03, PISA-01 and SAVO-02 were selected in the Run 2 sample. The main feature of the selected telescopes is the common clock distribution to the 2 TDC boards, provided by a dedicated card. In the next paragraphs the strategy to measure time and spatial resolution will be described and the need of a common clock to the TDCs will be clarified. In Run 3 the clock distribution card has been installed in all the other EEE telescopes and this allows us to perform the measurement with a complete set of telescopes and compare the results with Run 2 data. The last paragraph of this section will show the results on the efficiency measurement. The track selection is done by requiring χ^2 <10 and taking into account only events without clusters (MODIFICARE AMPLIANDO).

- ✓ section on track reconstruction to be modified (copied by other papers at the moment)
- ✓ section on performance written; to be slightly modified

Paper



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3.1 High Voltage stability

The high voltage (HV) applied to an MRPC, or generally to a RPC-based detector is a sensitive parameter for all the applications of these detectors to absolute particle flux measurements as well as for relative measurements performed over a long time period. The HV directly defines the working point of the detector, to be ideally fixed within the *plateau* region, 300-400 V beyod the knee of the efficiency curve and at the same time at the lowest allowed value, in order to limit the *dark rate*. This last parameter is fundamental for such detector, being in a 10 - 1000 KHz typical range. Any HV fluctuation beyond 300-400 V can set the working point of the chamber in a region before the knee, where also tiny fluctuations (tenths of volts) correspond to a few percent efficiency variations. The stability of the HV power supply chain of the EEE telescope is therefore fundamental for allowing the EEE telescopes to be sensitive to phenomena involving a few percent particle flux variations, such as solar activity surveys, and also for the search of very rare events, where a few percent efficiency decrease on all the chambers of a cluster of EEE telescopes drives the cluster to a 20-50% efficiency suppression.

The EEE telescopes are powered by DC-DC converters, with output voltage roughly a factor 2000 with respect to the driving low voltage (LV) (see section 2.1). Stand-alone LV power supply units, both commercial or custom engineered by the EEE Collaboration, provides the driving LV to the DC-DC converters. The core unit of the DC-DC converters are the EMCO Q-series, both positive and negative, with a 10 kV full scale output. The HV stability declared by the manifacturer is ±1 kV at full load (10 kV). The typical working voltage is 8-9 kV, thus very close to the full scale.

The temperature is an independent source of HV unstability for an RPC-based detector, being both the gain and the noise related to ionization phenomena and charge avalanche development in gas [6]. Two different approaches can be applied, also in parallel, for correcting HV fluctuations due to temperature variations. The first, already in operation in several EEE sites, is the temperature control of the environment where the telescopes are installed. The second is the online correction of the HV by stabilizing the "effective" HV applied to the chambers, that differs from the actual HV applied, as stated in [7].

In figure 4 the HV time-trend is shown for a random set of EEE telescopes. The blue, green and red lines represents the lower, middle and upper chambers, respectively. It is possible to see the HV stability in the chosen period. The differences among the HV applied to the chambers of the same telescope are related to the different plateau position for the various chambers. The EEE Collaboration is working on a solution to further improve the HV stability, by both evaluating more stable converters and designing a HV-LV feedback system for the online monitoring and correction of the HV applied to the chambers, in order to reach a few tenths volts HV stability target.

- ✓ section on HV stability written
- ✓ to be moved close to the section on the efficiency

Paper

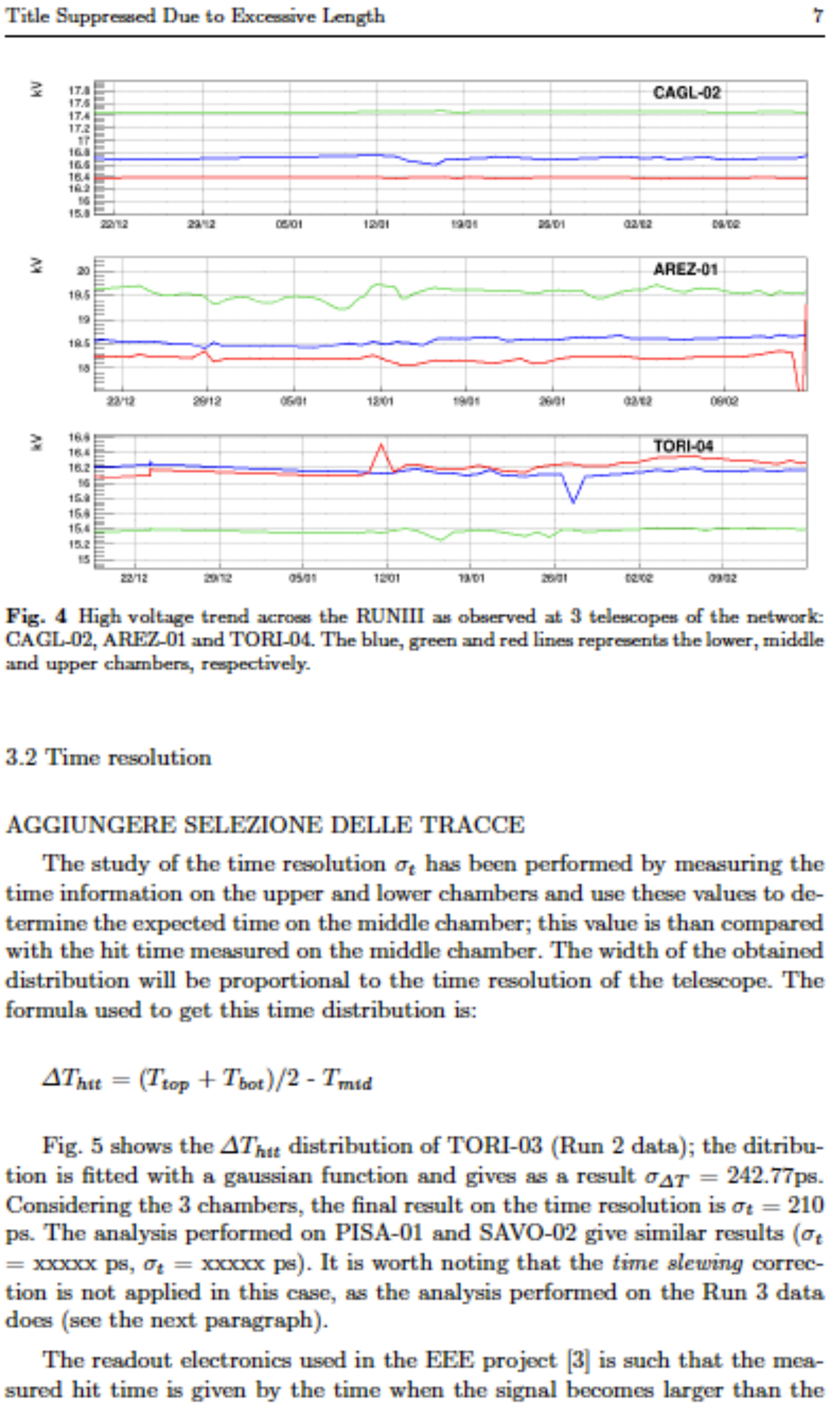

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Fig. 4 High voltage trend across the RUNIII as observed at 3 telescopes of the network: CAGL-02, AREZ-01 and TORI-04. The blue, green and red lines represents the lower, middle and upper chambers, respectively.

3.2 Time resolution

AGGIUNGERE SELEZIONE DELLE TRACCE

The study of the time resolution σ_t has been performed by measuring the time information on the upper and lower chambers and use these values to determine the expected time on the middle chamber; this value is than compared with the hit time measured on the middle chamber. The width of the obtained distribution will be proportional to the time resolution of the telescope. The formula used to get this time distribution is:

$$\Delta T_{htt} = (T_{top} + T_{bot})/2 \text{ - } T_{mtd}$$

Fig. 5 shows the ΔT_{htt} distribution of TORI-03 (Run 2 data); the ditribution is fitted with a gaussian function and gives as a result $\sigma_{\Delta T} = 242.77$ps. Considering the 3 chambers, the final result on the time resolution is $\sigma_t = 210$ ps. The analysis performed on PISA-01 and SAVO-02 give similar results (σ_t = xxxxx ps, σ_t = xxxxx ps). It is worth noting that the *time slewing* correction is not applied in this case, as the analysis performed on the Run 3 data does (see the next paragraph).

The readout electronics used in the EEE project [3] is such that the measured hit time is given by the time when the signal becomes larger than the

- ✓ section on time resolution written
- ✓ strategy for track selection to be added

Paper

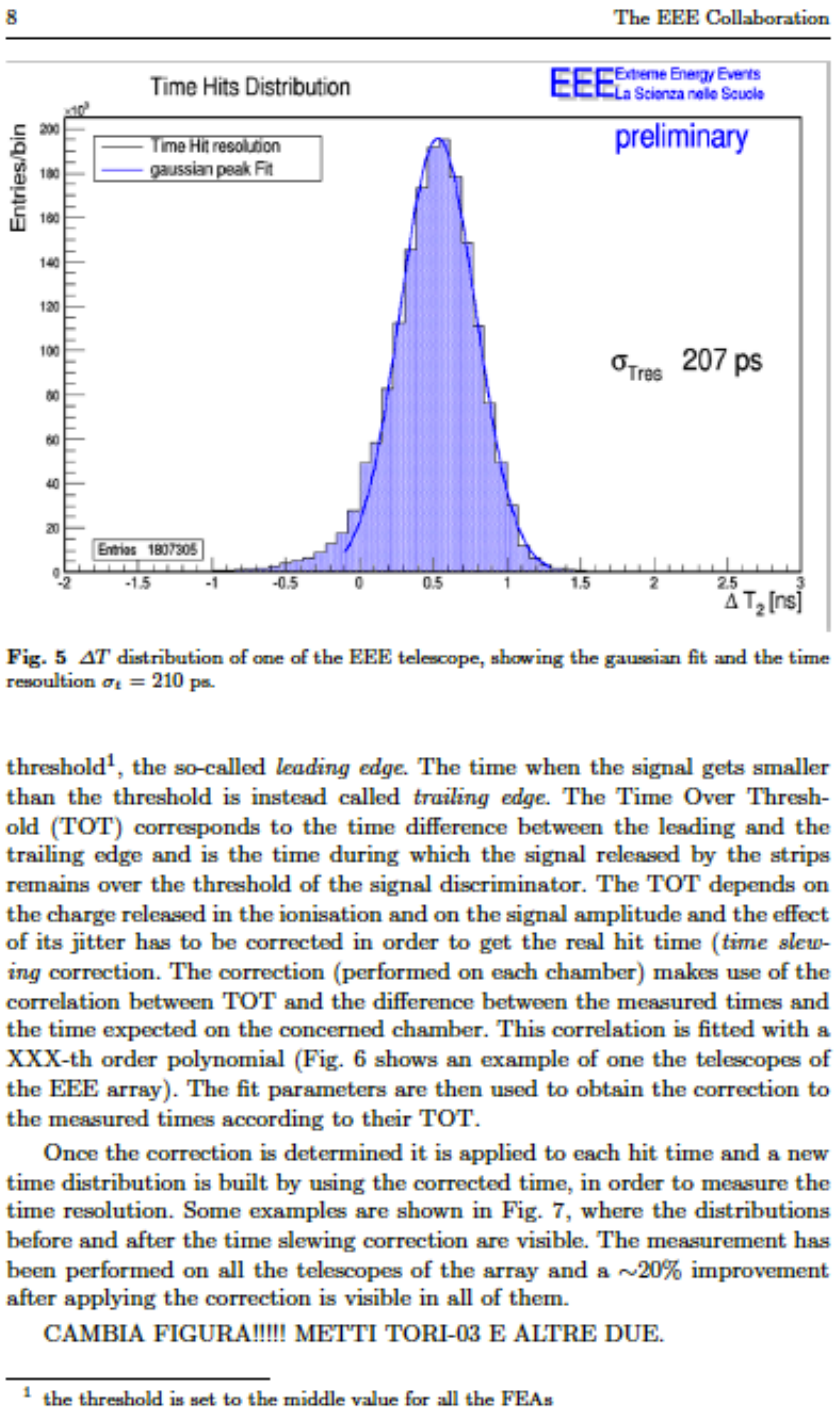

Fig. 5 ΔT distribution of one of the EEE telescope, showing the gaussian fit and the time resoultion $\sigma_t = 210$ ps.

threshold[1], the so-called *leading edge*. The time when the signal gets smaller than the threshold is instead called *trailing edge*. The Time Over Threshold (TOT) corresponds to the time difference between the leading and the trailing edge and is the time during which the signal released by the strips remains over the threshold of the signal discriminator. The TOT depends on the charge released in the ionisation and on the signal amplitude and the effect of its jitter has to be corrected in order to get the real hit time (*time slewing* correction. The correction (performed on each chamber) makes use of the correlation between TOT and the difference between the measured times and the time expected on the concerned chamber. This correlation is fitted with a XXX-th order polynomial (Fig. 6 shows an example of one the telescopes of the EEE array). The fit parameters are then used to obtain the correction to the measured times according to their TOT.

Once the correction is determined it is applied to each hit time and a new time distribution is built by using the corrected time, in order to measure the time resolution. Some examples are shown in Fig. 7, where the distributions before and after the time slewing correction are visible. The measurement has been performed on all the telescopes of the array and a ~20% improvement after applying the correction is visible in all of them.

CAMBIA FIGURA!!!!! METTI TORI-03 E ALTRE DUE.

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[1] the threshold is set to the middle value for all the FEAs

- ✓ section on time resolution written
- ✓ *time slewing* correction explained and results shown

Paper

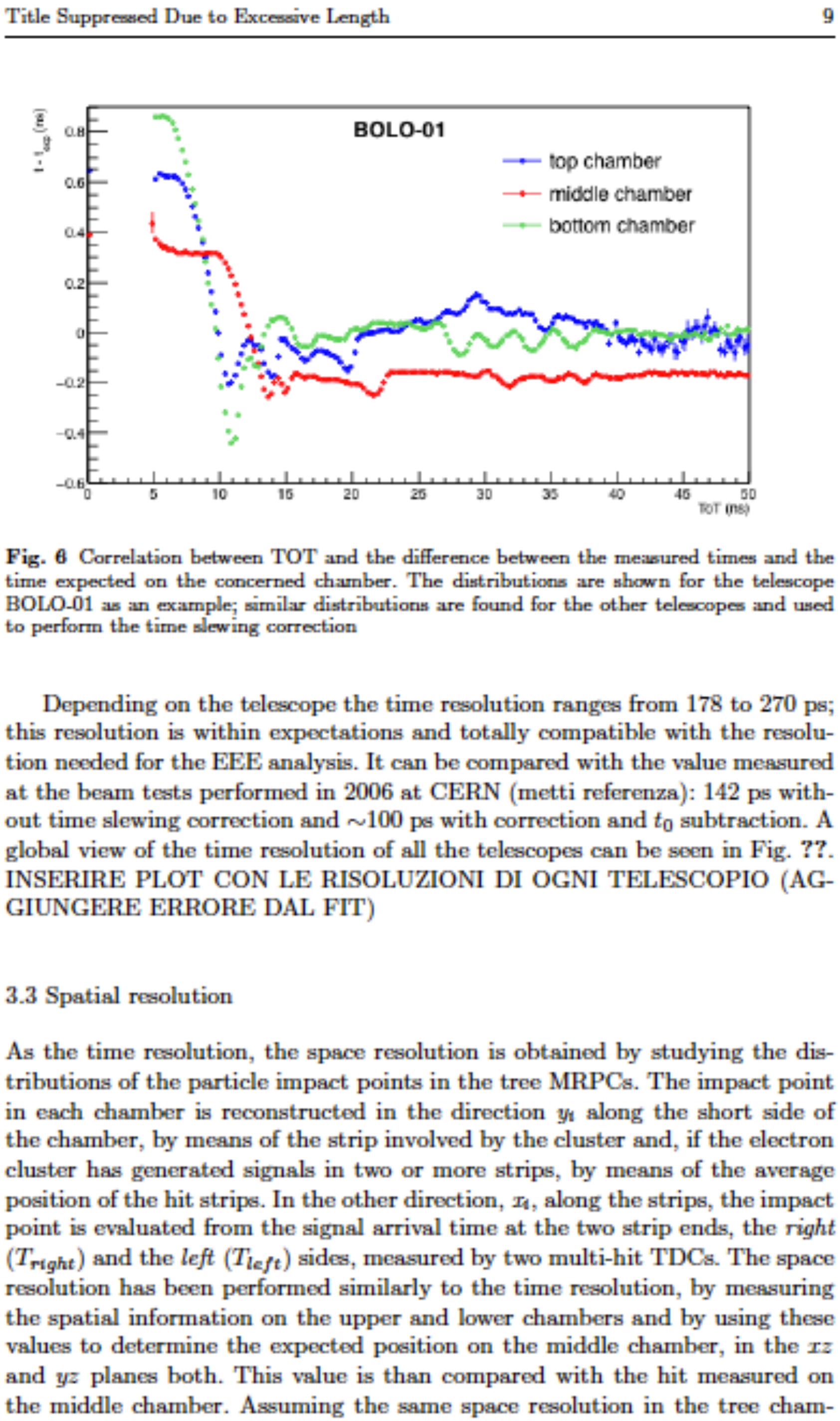

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Fig. 6 Correlation between TOT and the difference between the measured times and the time expected on the concerned chamber. The distributions are shown for the telescope BOLO-01 as an example; similar distributions are found for the other telescopes and used to perform the time slewing correction

Depending on the telescope the time resolution ranges from 178 to 270 ps; this resolution is within expectations and totally compatible with the resolution needed for the EEE analysis. It can be compared with the value measured at the beam tests performed in 2006 at CERN (metti referenza): 142 ps without time slewing correction and ~100 ps with correction and t_0 subtraction. A global view of the time resolution of all the telescopes can be seen in Fig. ??. INSERIRE PLOT CON LE RISOLUZIONI DI OGNI TELESCOPIO (AGGIUNGERE ERRORE DAL FIT)

3.3 Spatial resolution

As the time resolution, the space resolution is obtained by studying the distributions of the particle impact points in the tree MRPCs. The impact point in each chamber is reconstructed in the direction y_t along the short side of the chamber, by means of the strip involved by the cluster and, if the electron cluster has generated signals in two or more strips, by means of the average position of the hit strips. In the other direction, x_t, along the strips, the impact point is evaluated from the signal arrival time at the two strip ends, the *right* (T_{right}) and the *left* (T_{left}) sides, measured by two multi-hit TDCs. The space resolution has been performed similarly to the time resolution, by measuring the spatial information on the upper and lower chambers and by using these values to determine the expected position on the middle chamber, in the xz and yz planes both. This value is than compared with the hit measured on the middle chamber. Assuming the same space resolution in the tree cham-

- ✓ section on time resolution written
- ✓ plot t vs TOT to show the strategy for the *time slewing* correction
- ✓ plot with σ_t for all telescoped to be added
- ✓ section on spatial resolution written; to be slightly modified

Paper

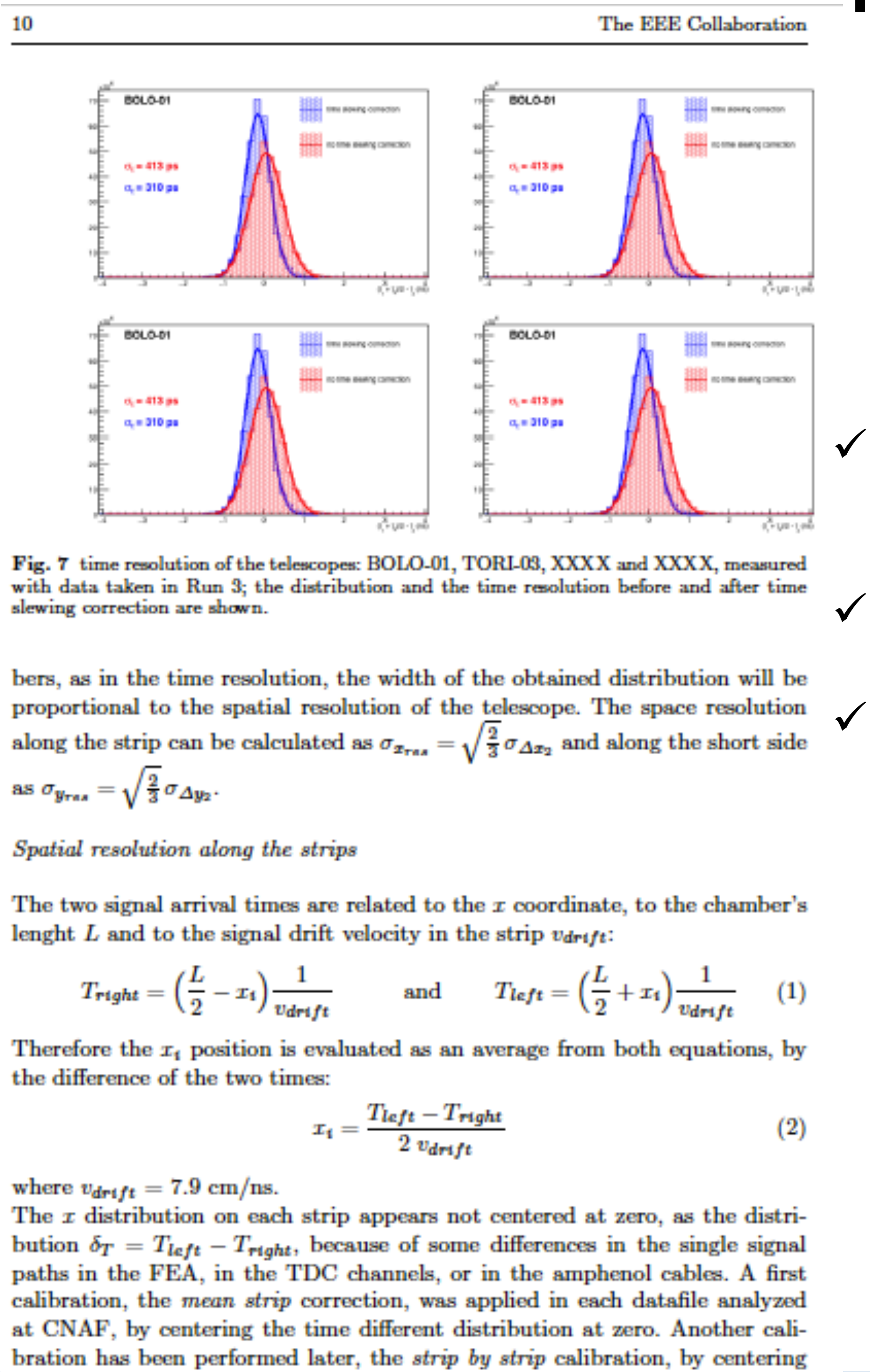

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Fig. 7 time resolution of the telescopes: BOLO-01, TORI-03, XXXX and XXXX, measured with data taken in Run 3; the distribution and the time resolution before and after time slewing correction are shown.

bers, as in the time resolution, the width of the obtained distribution will be proportional to the spatial resolution of the telescope. The space resolution along the strip can be calculated as $\sigma_{x_{res}} = \sqrt{\frac{2}{3}}\sigma_{\Delta x_2}$ and along the short side as $\sigma_{y_{res}} = \sqrt{\frac{2}{3}}\sigma_{\Delta y_2}$.

Spatial resolution along the strips

The two signal arrival times are related to the x coordinate, to the chamber's lenght L and to the signal drift velocity in the strip v_{drift}:

$$T_{right} = \left(\frac{L}{2} - x_t\right)\frac{1}{v_{drift}} \qquad \text{and} \qquad T_{left} = \left(\frac{L}{2} + x_t\right)\frac{1}{v_{drift}} \qquad (1)$$

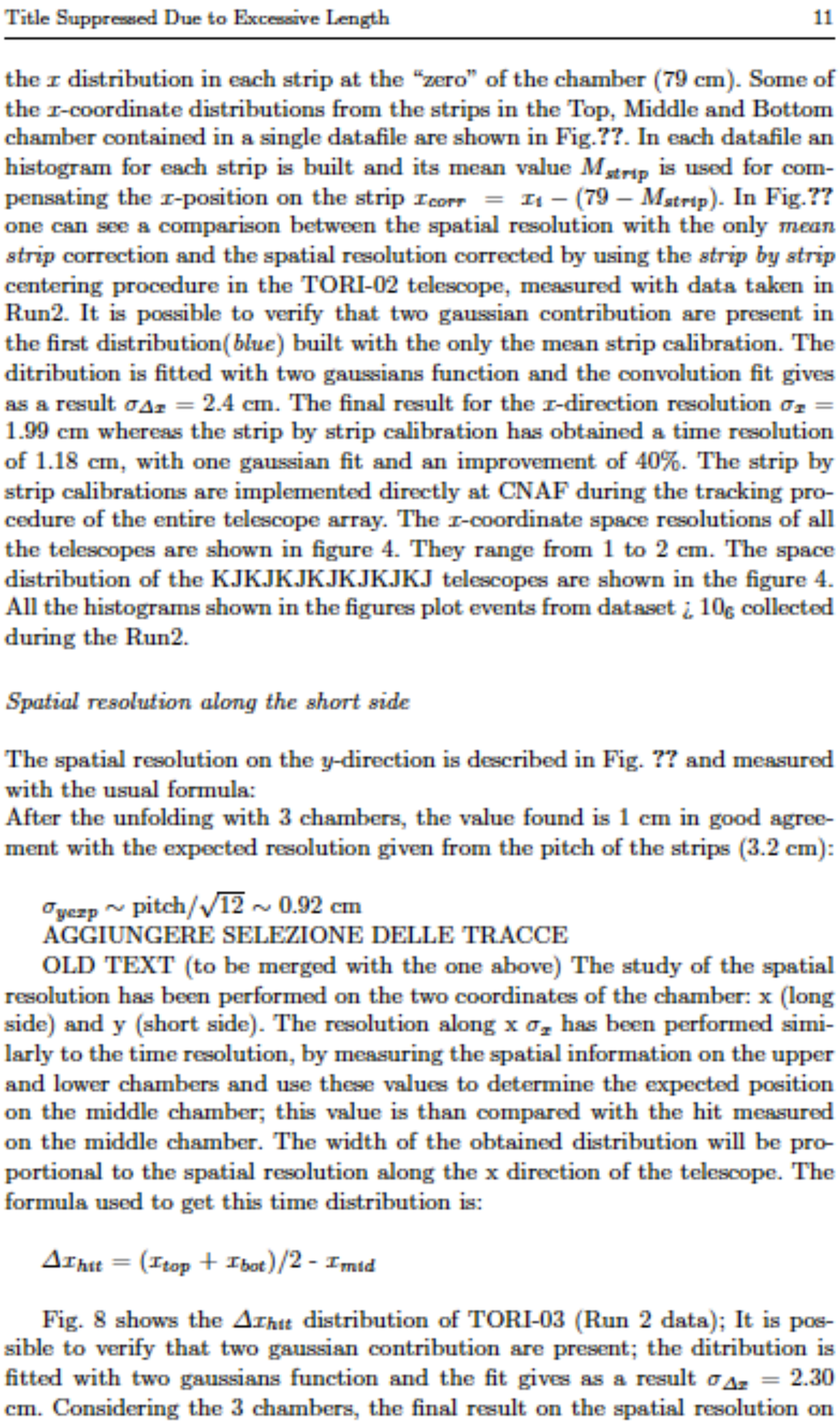
Therefore the x_t position is evaluated as an average from both equations, by the difference of the two times:

$$x_t = \frac{T_{left} - T_{right}}{2\, v_{drift}} \qquad (2)$$

where $v_{drift} = 7.9$ cm/ns.
The x distribution on each strip appears not centered at zero, as the distribution $\delta_T = T_{left} - T_{right}$, because of some differences in the single signal paths in the FEA, in the TDC channels, or in the amphenol cables. A first calibration, the *mean strip* correction, was applied in each datafile analyzed at CNAF, by centering the time different distribution at zero. Another calibration has been performed later, the *strip by strip* calibration, by centering

- ✓ plots of σ_t for the same telescope at the moment just as example (3 other telescopes will replace them)
- ✓ plot with σ_x and σ_y for all telescoped to be added
- ✓ section on spatial resolution written; to be slightly modified

Paper



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the x distribution in each strip at the "zero" of the chamber (79 cm). Some of the x-coordinate distributions from the strips in the Top, Middle and Bottom chamber contained in a single datafile are shown in Fig.??. In each datafile an histogram for each strip is built and its mean value M_{strip} is used for compensating the x-position on the strip $x_{corr} = x_1 - (79 - M_{strip})$. In Fig.?? one can see a comparison between the spatial resolution with the only *mean strip* correction and the spatial resolution corrected by using the *strip by strip* centering procedure in the TORI-02 telescope, measured with data taken in Run2. It is possible to verify that two gaussian contribution are present in the first distribution(*blue*) built with the only the mean strip calibration. The ditribution is fitted with two gaussians function and the convolution fit gives as a result $\sigma_{\Delta x} = 2.4$ cm. The final result for the x-direction resolution $\sigma_x =$ 1.99 cm whereas the strip by strip calibration has obtained a time resolution of 1.18 cm, with one gaussian fit and an improvement of 40%. The strip by strip calibrations are implemented directly at CNAF during the tracking procedure of the entire telescope array. The x-coordinate space resolutions of all the telescopes are shown in figure 4. They range from 1 to 2 cm. The space distribution of the KJKJKJKJKJKJKJ telescopes are shown in the figure 4. All the histograms shown in the figures plot events from dataset ¿ 10_6 collected during the Run2.

Spatial resolution along the short side

The spatial resolution on the y-direction is described in Fig. ?? and measured with the usual formula:
After the unfolding with 3 chambers, the value found is 1 cm in good agreement with the expected resolution given from the pitch of the strips (3.2 cm):

$$\sigma_{yexp} \sim \text{pitch}/\sqrt{12} \sim 0.92 \text{ cm}$$

AGGIUNGERE SELEZIONE DELLE TRACCE

OLD TEXT (to be merged with the one above) The study of the spatial resolution has been performed on the two coordinates of the chamber: x (long side) and y (short side). The resolution along x σ_x has been performed similarly to the time resolution, by measuring the spatial information on the upper and lower chambers and use these values to determine the expected position on the middle chamber; this value is than compared with the hit measured on the middle chamber. The width of the obtained distribution will be proportional to the spatial resolution along the x direction of the telescope. The formula used to get this time distribution is:

$$\Delta x_{hit} = (x_{top} + x_{bot})/2 - x_{mid}$$

Fig. 8 shows the Δx_{hit} distribution of TORI-03 (Run 2 data); It is possible to verify that two gaussian contribution are present; the ditribution is fitted with two gaussians function and the fit gives as a result $\sigma_{\Delta x} = 2.30$ cm. Considering the 3 chambers, the final result on the spatial resolution on

- ✓ plots of σ_t for the same telescope at the moment just as example (3 other telescopes will replace them)
- ✓ plot with σ_x and σ_y for all telescoped to be added
- ✓ section on spatial resolution written; to be slightly modified

Paper

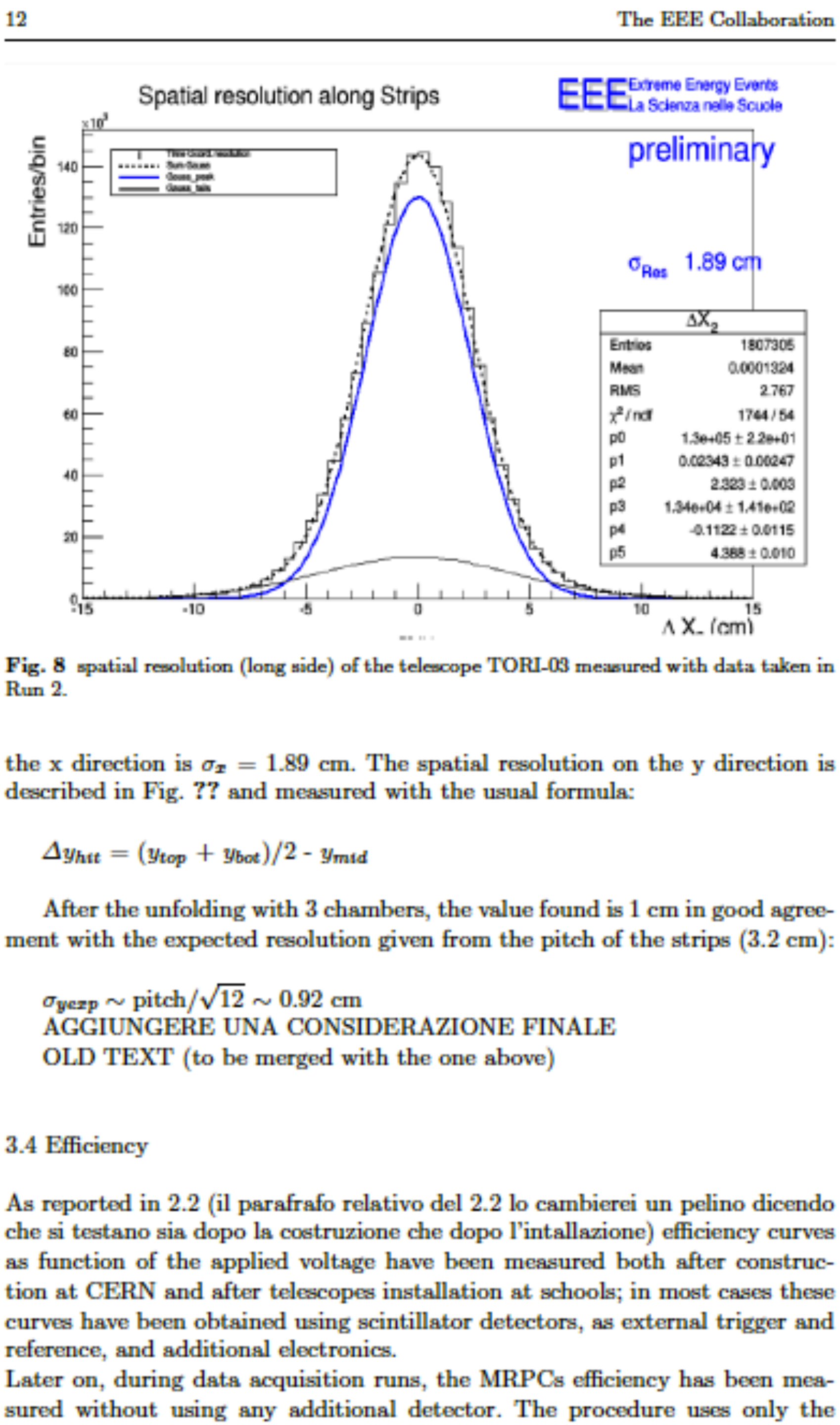

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Fig. 8 spatial resolution (long side) of the telescope TORI-03 measured with data taken in Run 2.

the x direction is $\sigma_x = 1.89$ cm. The spatial resolution on the y direction is described in Fig. ?? and measured with the usual formula:

$$\Delta y_{hit} = (y_{top} + y_{bot})/2 - y_{mid}$$

After the unfolding with 3 chambers, the value found is 1 cm in good agreement with the expected resolution given from the pitch of the strips (3.2 cm):

$$\sigma_{yexp} \sim \text{pitch}/\sqrt{12} \sim 0.92 \text{ cm}$$

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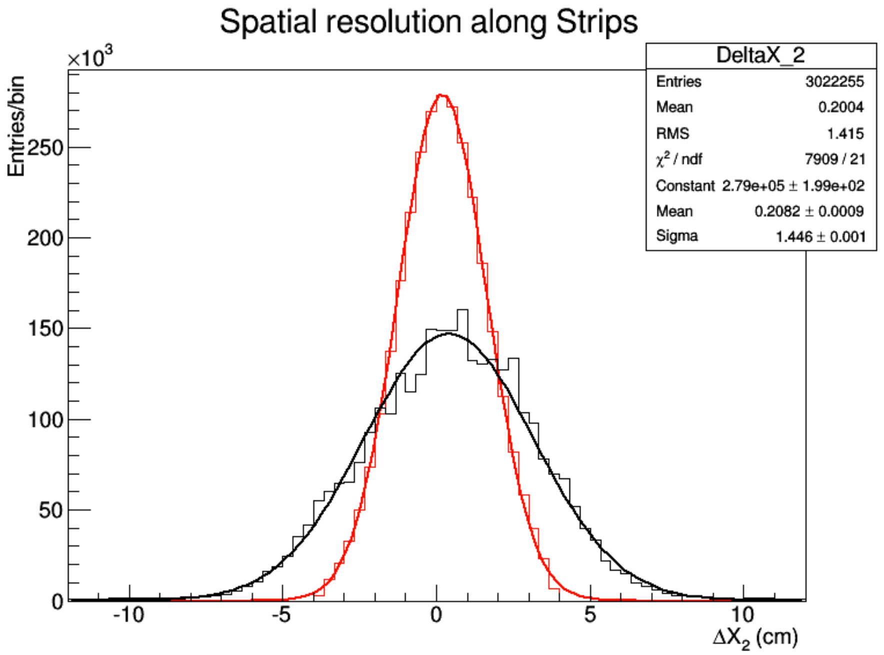
OLD TEXT (to be merged with the one above)

3.4 Efficiency

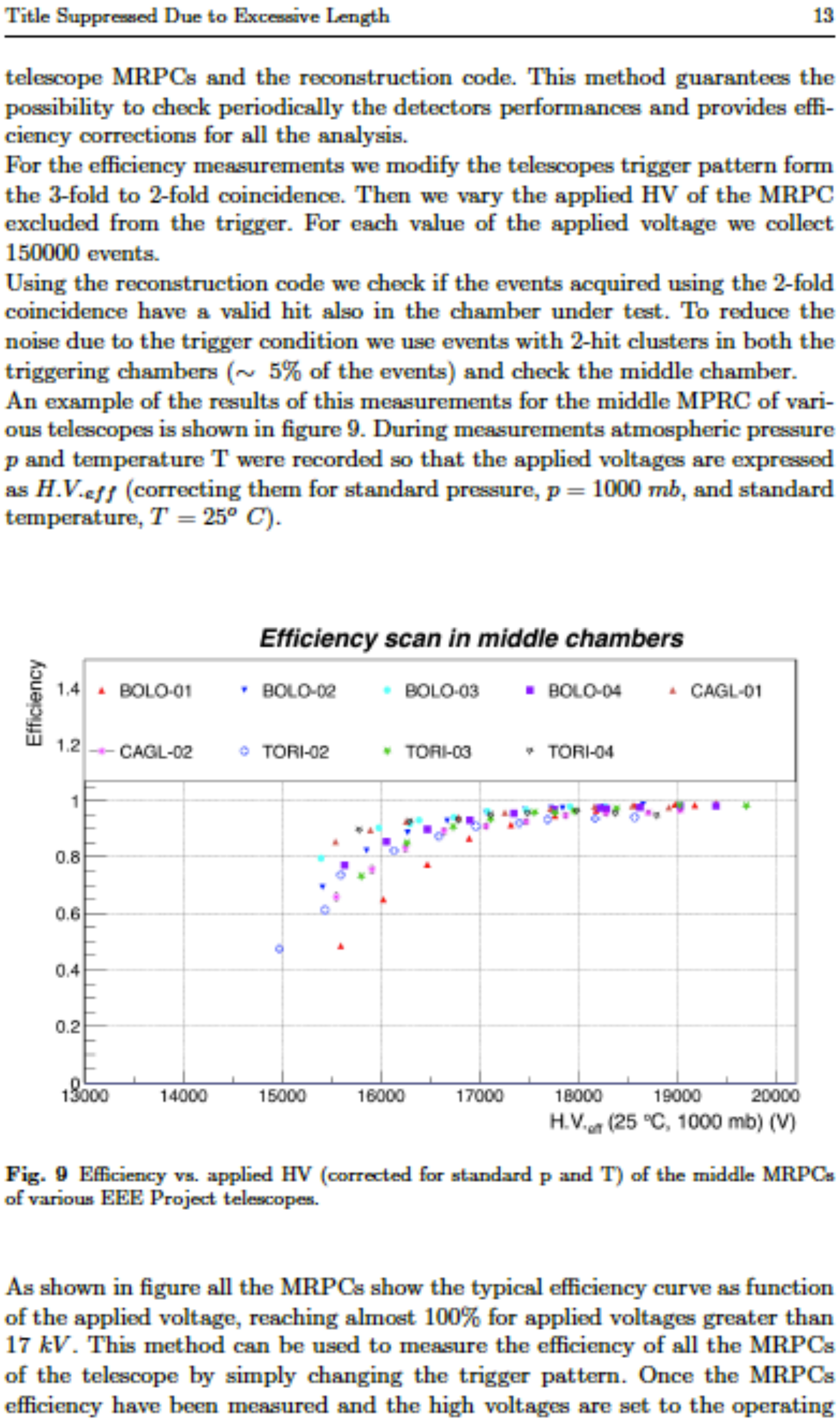
As reported in 2.2 (il parafrafo relativo del 2.2 lo cambierei un pelino dicendo che si testano sia dopo la costruzione che dopo l'intallazione) efficiency curves as function of the applied voltage have been measured both after construction at CERN and after telescopes installation at schools; in most cases these curves have been obtained using scintillator detectors, as external trigger and reference, and additional electronics.
Later on, during data acquisition runs, the MRPCs efficiency has been measured without using any additional detector. The procedure uses only the

- ✓ plot with σ_x to be added
- ✓ plot showing the improvement using the new version of the analyzer to be added?



- ✓ section on efficiency with internal trigger written

Paper



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telescope MRPCs and the reconstruction code. This method guarantees the possibility to check periodically the detectors performances and provides efficiency corrections for all the analysis.

For the efficiency measurements we modify the telescopes trigger pattern form the 3-fold to 2-fold coincidence. Then we vary the applied HV of the MRPC excluded from the trigger. For each value of the applied voltage we collect 150000 events.

Using the reconstruction code we check if the events acquired using the 2-fold coincidence have a valid hit also in the chamber under test. To reduce the noise due to the trigger condition we use events with 2-hit clusters in both the triggering chambers (~ 5% of the events) and check the middle chamber.

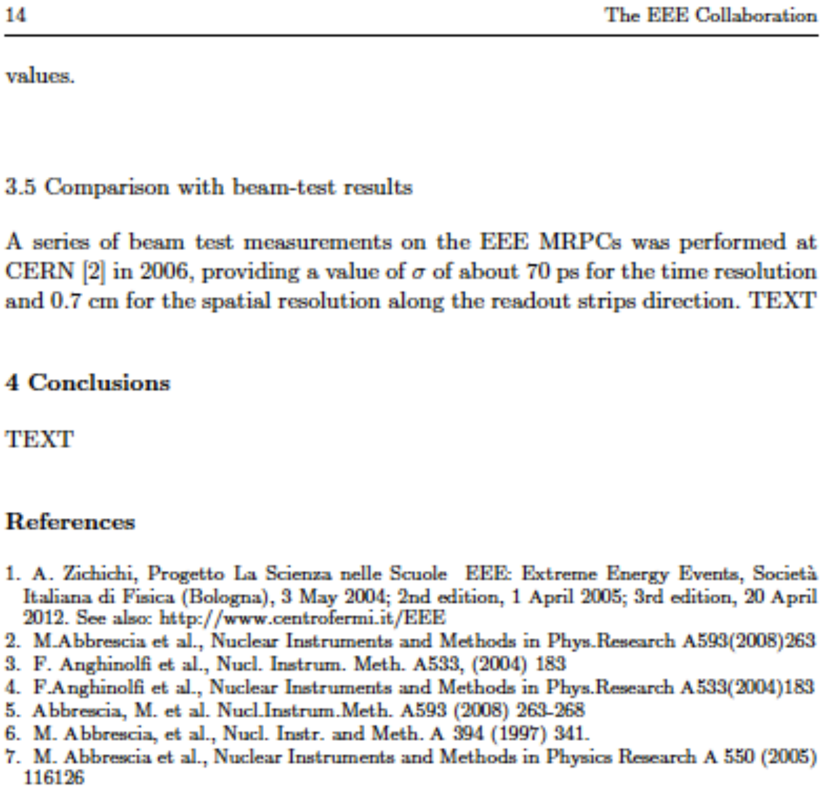
An example of the results of this measurements for the middle MPRC of various telescopes is shown in figure 9. During measurements atmospheric pressure p and temperature T were recorded so that the applied voltages are expressed as $H.V._{eff}$ (correcting them for standard pressure, $p = 1000\ mb$, and standard temperature, $T = 25^o\ C$).

Fig. 9 Efficiency vs. applied HV (corrected for standard p and T) of the middle MRPCs of various EEE Project telescopes.

As shown in figure all the MRPCs show the typical efficiency curve as function of the applied voltage, reaching almost 100% for applied voltages greater than 17 kV. This method can be used to measure the efficiency of all the MRPCs of the telescope by simply changing the trigger pattern. Once the MRPCs efficiency have been measured and the high voltages are set to the operating

- ✓ section on efficiency with internal trigger written
- ✓ comparison with beam tests in 2016 mentioned
- ✓ section on efficiency with external trigger to be written

Paper



values.

3.5 Comparison with beam-test results

A series of beam test measurements on the EEE MRPCs was performed at CERN [2] in 2006, providing a value of σ of about 70 ps for the time resolution and 0.7 cm for the spatial resolution along the readout strips direction. TEXT

4 Conclusions

TEXT

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✓ conclusions to be written

✓ bibliography to be completed

Conclusions

- ✓ data from Run 2 and Run 3 provide good data for the paper
- ✓ a few plots to be included (soon available)
- ✓ number of analyzed tracks (likely ~1 billion) to be included
- ✓ finish writing in the next 2 weeks